FUNDAMENTALS OF DESIGN AND MANUFACTURING

Specially for A.M.I.E. Section-A (Diploma and Non-Diploma) Scheme effective from Summer 2005 also useful for B.E./B.Tech. and other Competitive Examinations

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FUNDAMENTALS OF DESIGN AND MANUFACTURING

GROUP A

Engineering design process and its structure. Identification and analysis of need, product design specifications, standards of performance and constraints

Searching for design concepts, morphological analysis, brainstorming. Evaluation of design concepts for physical reliability, economic feasibility and utility

Detailed design; design for manufacture, assembly, shipping, maintenance, use, and recyclability

Design checks for clarity, simplicity, modularity and safety Standardization and size ranges Reliability and robust design. Design organisation and communication, technical reports, drawings, presentations and models.

Concept of manufacturing, classification of manufacturing processes Fundamentals of casting Basic understanding of commonly used casting processes (sand casting, investment casting and permanent mould casting processes).

Fundamentals of metal forming; hot and cold working, basic understanding of primary metal forming processes (rolling, forging, extrusion and drawing processes, punching and blanking)

GROUP B

Fundamentals of metal cutting; tool-work interaction for production of machined surfaces. Classification of machining processes. Basic machining operations (turning, shaping, planning, drilling and milling processes).

Fundamentals of grinding and finishing; overview of unconventional machining processes; fundamentals of welding processes; introduction to primary welding and allied processes, selection of manufacturing processes. Design for manufacturability.

Need for integration–commerical, economic and technological perspective; basic tools of integration; concept of a system. Introduction to information technology and its elements.

Introduction to group technology; introduction to simulation and database management systems.

Elements of integration–controllers, sensors, robots, automated machines; AGVs, AS, RS, etc.

Product and process design for integration; design for economic manufacturing; design for manufacturing integration.

Introduction to computer aided process planning; selection of machine tools.

Preface

This treatise on **"Fundamental of Design and Manufacturing"** has been written in general for students preparing for B.E./B.Tech and other competitive examinations but in particular for the students desirous of passing **A.M.I.E–Section A** (India) Special care has been taken to present the subject matter in lucid, direct and easily understandable style

The book comprises 21 chapters. Each chapter is saturated with much needed text supported by suitable figures whereever necessary. At the end of each chapter, **"Questions with Answers, Highlights, Objective Type Questions** and **Theoretical Questions** have been added. Besides this a **"Questions' Bank"** (including ***Short Answer Questions*** and ***Objectives Type Test Questions)*** has also been incorporated at the end of the book to make it a comprehensive and complete unit in all respects.

The author's thanks are due to his wife Ramesh Rajput without whose cooperation and encouragement, this book would have never been materialised.

In the end the author wishes to express his gratitude to Sh. B.S. Kohli for taking great pains in bringing out this book in a good shape and in a short span of time

Although every care has been taken to make the book free of errors, yet the author shall feel obliged, if any errors present are bought to his notice.

R.K. Rajput
(Author)

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1.1. INTRODUCTION TO ENGINEERING DESIGN

1.1.1. Definition

• **Design** *is a creative activity — it is the creative part of engineering.*

When applied to engineering, ***'creativity'*** *is the ability to conceive basic innovations, to preceive in a situation those problems that can readily be solved, to devise solutions to new problems, and to combine familiar concepts in unusual ways.*

• According to *Dieter :* "**Design** *establishes and defines solutions to pertinent structures for problems not solved before, or new solutions to problems which have been previously solved in a different way".*

According to *Dym.* "**Design** *is the systematic intelligent generation and evaluation of specifications for artifacts whose form and function achieve stated objectives and satisfies specified constraints".*

The purpose of design is to create a new product or redesign an existing product that turns into profits and benefits to society. The *design ability requires both science and art.* The science can be learnt through systematic study and methods for the course, but art can only be learnt by doing design or doing practice with total dedication.

1.1.2. Design for Production

The following *two functions pertain to design production :*

1. Product design. The product design function involves the development of *"specifications"* of a product that will be functionally sound, have *"eye appeal"* and will give satisfactory performance for a sufficient life span.

2. Process design. The process design function includes developing the method of manufacture of the product so that it can be produced at a *competitive price*. This work will require the following

- The sequence of operations and inspections to be performed.
- Jigs, fixtures, gauges etc. needed to produce the work
- The establishment of allowed elemental times for performing the work.

1.1.3. Characteristics of a Good Designer

The important characteristics of a good designer are :

1. Technical competence.
2. Initiative.
3. Confidence.
4. Intensity.
5. Capacity to synthesize.
6. Ability to observe with discernment.
7. Active curiosity.
8. Motivation to design for the pleasure of accomplishment

1.1.4. Roadblocks to the Creative Approach in Designing

Following are the *main roadblocks to the creative approach in designing* :

1. Unwillingness to consider new approach.
2. Unwillingness to change the accepted form.
3. Fear of making a mistake.
4. Overinvolvement with the standard conceptions of function.
5. Desire to conform or adopt to standard patterns.
6. Inability to collect complete information
7. Unwillingness to reject an old workable solution.
8. Lock of confidence resulting from lack of knowledge.
9. Unwillingness to appear to criticise.
10. Fear of authority and/or distrust of associates.
11. Unwillingness to be different.
12. Overconfidence due to past experience.

1.2. DESIGN ASPECTS

Following are *some important aspects of design :*

1. Need analysis.
2. Feasibility study.
3. Preliminary design.
4. Detailed design.

1. Need analysis. Whenever there is a need for any product/facility the problem of design arises. Thus, first step in any design is the *recognition of the need. **Examples :*** (*i*) A higher capacity machine for a process may be needed, due to need for higher productions; (*ii*) A fuel efficient engine may be needed because of mounting fuel costs

— The initial primitive statement of need may be merely an expression of opinion However when it occurs, it merits considerable study to ascertain that need does exist and that it represents a realistic interpretation of the situation
— Sometimes design may be necessary is view of needs, which are anticipated in future. Often development of new materials calls for modification of existing designs

- *The **need analysis** concludes with a specification, which provides the starting point for the feasibility study* The statement may vary from a terse statement to a highly detailed set of requirements

2. Feasibility study. The *feasibility of a design must be checked at various stages* The delayed detection of some unexpected snag may prove to be disastrous Concord supersonic passenger aircraft is an example of failure due to poor techno-economic feasibility

- The feasibility study, through the analysis of several worktable alternate solutions, establishes the design concept as something which can in fact be realised and accepted
- Whenever it is felt that the approach is physically possible, its economic feasibility as well as public acceptability must be investigated.

3. Preliminary design. The objective of preliminary design is to select the best solution from the possible alternatives While selecting the best alternative, the comparison has to be made in terms of certain criteria and constraints already established during the earlier phases

- The choice finally made in the preliminary design phase is a tentative one, the next step is the detailed design

4. Detailed design. In detailed design the complete specifications of all the components are assigned, the details are finalised including preparation of working drawings (to be handed over to the manufacturer)

In general, this phase is far less flexible than the various preliminary ones

— Sometimes, it may be necessary to construct a prototype of the product in order to ensure that it lives upto the expected standards
— Sometimes a major overhaul necessitating that the chosen solution be scrapped, may also occur

1.3. MODEL

The concept of '*model*' and '*modelling*' is a highly developed field of science Models are used in all fields, *e g* , engineering, biology, physics, biochemistry etc

A **model** *is representation of a system in a convenient fashion so that conjectures made about the performance of the system can be readily tested*

Scientific methods used by engineers involve the representation of the real world on his desk in symbolic form or in the laboratory, known as **modelling.**

Various types of models are used to represent the real situation involving different degrees of abstraction. The main classification are

1. Ionic models. These models represent things as they appear, and so sketches and drawings of all types fall under this category

2. Analogic models. These models represents specific features of the design by using an analogy. Schematic diagrams and flow diagrams are of type as are circuit diagrams

These models can also be used to visualise properties that are abstract in nature such as bending moment and shear force.

3. Symbolic models. These models describe some aspects of product by using words, numbers or mathematical symbols. A list of parts bill of materials fall into this category, but mathematical equation describing some aspects of product's behaviour such as Rankine Gordon equation on complex algorithms made up of many mathematical equations and therefore are also symbolic form of models.

A symbolic model is also important because it leads to quantiative results.

- The models, invariably, involve some simplifying assumptions However, the usefulness of the models depends on how realistic these assumptions are. Based on his knowledge of the real world the designer will study the models and will find which are most suitable for his purpose.

1.4. PRINCIPLES OF GOOD ECONOMIC DESIGN

Following are the *principles of good economic design :*

1. To avoid all the unnatural body positions.
2. To divide the work between different limbs of body.
3. To avoid "standing position at work", if possible.
4. To avoid torsional loads as far as possible.
5. To have working area of proper height, both for sitting and standing positions.
6. To provide adequate light in the working area.
7. To locate the work requiring constant visual control in such a way as to allow a comfortable head position to the worker.
8. To minimise the number of groups of muscles required to perform a work.

1.5. CLASSIFICATION OF DESIGNS

Depending upon the methods used, the designs may be *classified* as follows :

1. Elemental design	....	Design of any element of the mechanical system like *connecting rod* of an I.C. engine.
2. System design	....	Design of any complex mechanical system like *motor car.*
3. Rational design	....	Mathematical design based upon the principles of the machines.
4. Optimum design	....	The best design from the point of view of the most significant effect.
5. Emperical design	....	Based on the practice and past experience.
6. Industrial design	....	Based on the production aspects, to manufacture any machine element in the industry.
7. Computer design.		

1.6. DESIGN PROCEDURE

In designing any machine part, it is very difficult to follow a rigid procedure Following *logic procedure of design may be adopted :*

1. Mention the purpose for which the job is to designed.
2. Draw a sketch of the job showing its use.
3. Draw the design diagram of the job in simplified form
4. Determine the forces acting upon the job during machining operation
5. Select suitable material for the job
6. Determine the factor of safety and allowable stresses of the material, for the safe working of the job
7. Select/consider the manufacturing processes for the manufacture of the job
8. Calculate the size of each member of the job.
9. Draw an assembly drawing of the job.
10. Finally, prepare a detail drawing of each component of the job showing dimensions, manufacturing accuray, surface finish and other data pertinent to its manufacture.

Many machines elements (*i e.*, screws, bolts, keys, rolled sections etc.) of standard sizes are cheaply and readily available in the market, the designer should give preference to these parts/elements as far as possible

1.7. PROCESS PLANNING

1.7.1. General Aspects

Process planning may be *defined* as .

"The sub-system responsible for the conversion of design data to work instruction"

Or

"That function within a manufacturing facility which establishes the processes and process parameters to be used (as well as those machines capable of performing these processes), in order to convert a piece-part from its initial to a final, that is predetermined on a detailed engineering drawing".

- *Process planning is an* intermediate stage between designing the *product and manufacturing it.*
- It is a *staff activity.* It may constitute a department or alternatively may be considered a sub-group which, along with other sub-groups such as plant layout, tool design etc. will make up a manufacturing staff of manufacturing services department. Either of these plans accords with accepted organisational principles
- *The process planning begins where the product design ends.* However, the basic process planning must be during the product design stages where selection of materials and initial forms, such as casting, forging, and die casting, take place. The accepted end point for product design is manifested by the drawing release, which summarises the exact specifications of what is to be made. Process planning takes over from this point and *develops the broad plan of manufacture for the part or product*

Process planning takes as its inputs the drawings or other specifications, which indicate what is to be made and also the forecasts, orders or contracts which indicate how many are to be made.

1.7.2. Information Required to do Process Planning

For carrying out process planning the following information is required

1. Quantity of work to be done along with product specifications
2. Quantity of work to be completed
3. Availability of equipment tools and personnel.
4. Sequence in which the operations will be performed on the raw material.
5. Names of equipment on which the operations will be performed and when
6. Standard time for each operation

1.7.3. Procedure of Process Planning

Following *steps are involved in process planning* .

1. To prepare working drawings.
2. To decide whether to make or to buy
3. To select manufacturing process.
4. To select machine capacity and machine/equipment.
5. To select materials.
6. To select jigs, fixtures and other attachments
7. To carry out operation planning and decide tooling requirements.
8. To prepare documents such as operation and route sheets etc

1.7.4. Types of Process Planning

The process planning may be of the following types :

1. Manual process planning
2. Automated process planning
3. Generative process planning.

1. Manual process planning :

The manual process planning (also known as *man-variant process planning*) is the commonest type of planning used now-a-days. Planning of operations to be used to produce a part requires knowledge of the following two groups of variables :

(*i*) The part requirements (as per engineering);

(*ii*) The available machines and processes, and the capabilities of each process.

Once these variables are known, the planner selects the combination of processes based on the *criteria : 'Production cost or time'* and *'machine utilisation and routing'*.

- Invariably this type of process planning becomes a boring and tedious job. It produces erroneous process plans. This, coupled with the labour intensity of man-variant planning has lead many industries to investigate the *automation* of process planning.

2. Autotmated process planning :

Fig. 1.1 shows a completely automated process planning system. The block labelled LOGIC would include the capability to scan and interpret the drawing to convert this information into process requirements and to select machines, tools and operations to yield an economically acceptable product.

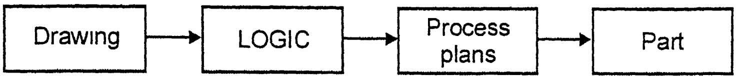


Fig. 1.1. Automated process planning system.

- Several developments in *computer-aided process planning* have focused on eliminating the process planner from the entire planning functions Computer aided process planning can *reduce* some of the decision making required during a planning process.

'Computer-aided process planning' claims the following ***advantages :***

(*i*) Reduced process planning time
(*ii*) Reduced skill required of a planner.
(*iii*) Increased productivity
(*iv*) More consistent plans can be created.
(*v*) More accurate plans can be produced
(*vi*) Both process planning and manufacturing costs can be reduced

3. Generative process planning : संश्लेषण

"Generative process planning" may be defined *as a system that synthesizes process information in order to create a process plan for a new component automatically.* Process plans are created from information available in a manufacturing data base, with little or no human intervention.

The process planning consists of the following *four steps*

(*i*) To describe a part in detail.
(*ii*) To describe a catalogue of processes available to produce parts
(*iii*) To describe the machine tool(s) that can perform these processes.
(*iv*) To create the software to inspect the part, and available machinery to determine whether all three are compatible

Advantages :

(*i*) New components can be planned as easily as existing components
(*ii*) It can potentially be interfaced with an automated manufacturing facility to provide detailed and up-to-date control information.
(*iii*) Consistent process plans can be generated rapidly.

1.8. IDEONOMICS IN DESIGN

1.8.1. Introduction

Ideonomics *is defined as the branch of science which is concerned with the generation of* ideas, their collection, *analysis and presentation.*

Ideation *means the process of generation of ideas.*

The following *elements* are involved in the process of ideonomics :

(*i*) Definition or statement of the problem.

(*ii*) Analysing the problem.

(*iii*) Developing alternate solutions.

- Ideation
- Creativity
- Modification
- New approaches.

(*iv*) Selecting the best solution.

(*v*) Implementation of the ideas

(*vi*) Verification of ideas.

1.8.2. Types of Ideas

Ideas can be of the following *types :*

1. Developed ideas. These are existing ideas but are standardised one and are used as it is for solving the problem.

2. Adaptive ideas. These are also existing ideas for similar applications and are *adopted with slight modifications* for solving the problem.

3. New ideas.

(*i*) Preliminary stage.

(*ii*) Working stage

(*iii*) Final stage

- In this case, the ideas for the problem are *not existing but are generated from the scratch* The new ideas are *generated by the application of scientific laws, common sense, logical reasoning and creative thinking.*

1.8.3. Methods of Accumulating Ideas

Following are the methods of accumulating ideas :

1. Individual approach
2. Team approach
3. Research method
4. Survey method.

1. Individual approach. In this method an individual engineer working independently on a problem tries to collect as many ideas as possible for solving the problem.

- The *disadvantage* of this method is that since the knowledge and expertise of an individual is limited, therefore, *only simple and small problem can be solved.*

2. Team approach. In team approach method, *many specialists in a variety of fields work together towards a common goal.* Generally, a team leader is made responsible to make job assignment and moderate all discussions.

- This type of approach is *required for designing complex equipment.*

3. Research method. In this case, the ideas are obtained through research methods attempted for similar situation earlier. These ideas can be modified to meet the current requirement. The

various ways which provide ideas/solutions for further analysis are :

— Technical journals

— Magazines

— Periodicals

— Manufacturers brochures

— Professional bodies and consultants.

4. Survey method. In this method, opinion and reactions from experts or consumers concerning 'preliminary design' and 'proposed design' are collected for further analysis

1.9. NEED HEEDOLOGY

1.9.1. Introduction

Need *is a personal, unfilled vacancy which determines and organises all psychological and behavioual activities in the direction of fulfilling the vacancy*

- *Need is the starting point in design* If there is no need, then there is no question of design or new ideas. Recognising a need is itself a creative process.

The beginning of any designing process is the recognition of need. The source from which need preception results, are as varied as the needs themselves

— The designer may recognize a need on his own, or it may be communicated to him by his employer or customer.

— Needs usually arise from dissatisfaction with the existing situation. They may be *to reduce the cost, increase reliability or performance or just change because the public has become bored with the product.*

- While designing a consumer product, the designer should not only assess the current needs but also future needs of the consumer. The consumer needs should be considered at all stages of design.

1.9.2. Types of Needs

The needs may be *categorised* as follows ·

1. User needs :

(*i*) *Performance need.* It deals with what the design should do when it is completed and in operation.

(*ii*) *Time need.* It includes all time aspects of the design, especially the schedule for the project. It has to ideals with such factors as when the design is needed and when it will become absolete.

(*iii*) *Cost need.* It pertains to all monetary aspects of the design.

2. Human needs :

(*i*) *Physiological needs.* These include hunger, thirst, sleep, sex, shelter and exercise.

(*ii*) *Safety and security needs.* These include protection against danger, deprivation and threat.

(*iii*) *Social needs.* These needs relate to love and esteem by others and include belonging to groups, group identity, and social acceptance

(*iv*) *Psychological needs.* They relate to self-esteem, self respect, accomplishment and recognition.

(*v*) *Self-fulfilment needs.* These relate to the realisation of one's full potential through self-development, creativity and self expression

1.9.3. Statement of Need

- The statement of need is quite different from identification of the problem The *problem is more specific The statement of need must be translated into definition of the problem* It must include all the specifications for the product that is to be designed The specifications are the input and output quantities, the characteristics and dimensions of the space the thing/product must occupy and all the limitations on these quantities
- *The statement of the need is most important because that only decides the definition of the problem*

1.9.4. Identification of Need

The object of identification is to *identify the problem* which has high priority and should be feasible *Identification is a mixture of both formal and informal process* For identification of problem, the following points need be considered :

(*i*) To identify the economical aspects of the problem.

(*ii*) To identify the data available with different agencies related with problem

(*iii*) To identify various systems like electrical, mechanical, chemical, political etc

(*iv*) To identify the topographical maps, geological survey etc for that problem

(*v*) The need of the problem should be valid and hence identify the project goal.

1.9.5. Identifying Customer Needs

One of the key activities of concept development phase is to "Indentify customer needs". The development of any product is not justified without clearly and properly identifying customer needs Identifying customer needs is the work of marketing team of an enterprise and to pass it on to the design and development team of the organisation Following are the *main objectives* of this methodology :

(*i*) To ensure that the product is focused on customer needs.

(*ii*) To identify latent or hidden needs as well as plainly stated needs.

(*iii*) To provide a fact base for justifying the product specifications.

(*iv*) To create an appropriate record of the needs activity of the development process.

(*v*) To ensure that no critical customer need is missed or forgotton.

(*vi*) To develop a common understanding of customer needs among the development team members.

- The philosophy behind identifying of customer needs is *to create a high quality information channel that runs between the customer of target market and product development team.*

1.9.6. Need Analysis

Need analysis *is the process of transforming need statements into statements of goals.*

After the designer agrees the preliminary need statement, he proceeds to analyse that need to obtain as complete definition as possible Here, there are usually two aspects in obtaining this definition, *e.g.*, the *specifications* and performance parameters or *standards of performance* These include the full details or particulars pertaining to the product and this leads to the analysis of need by a design engineer.

The need analysis can be illustrated diagrammatically as shown in Fig 1 2.

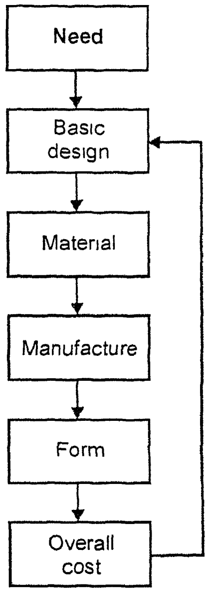


Fig. 1.2. Need analysis.

Requirements of need analysis :

Following are the *requirements* of need analysis .

1 To start with well defined need

2 To identify the resources which are required and which are available

3 To quantify the constraints clearly

4 To formulate some methods by which the results can be judged

5. To analyse the need thoroughly by surveying the past, present and future market.

Purpose of need analysis :

The main purposes of need analysis are

1. Satisfaction of customer. The customer gets satisfied when the following conditions are fulfilled .

(*i*) The product functions smoothly, easily and correctly

(*ii*) Low cost.

(*iii*) Pleasant get up of the product

(*iv*) High degree of accuracy.

2. Return in terms of profit. Return in terms of profit is achieved when the following conditions are fulfilled ·

(*i*) Manufacturing process adopted is easy and smooth.

(*ii*) Suitable to manufacture with use of standard components.

(*iii*) Cost of other factors involved in manufacturing the product are minimised.

Points to be considered while analysing a need :

The following points should be considered while *analysing a need*

1. To check the suitability of need in accordance to the society requirements.

2 To always keep in mind the future needs

3. To collect all information available with regard to spending habit of consumers, social behaviour etc to analyse need better.

4. To avoid imposing any solution on consumers as ultimately they are the real users of product.

5. To follow carefully the trends in the market, with special reference to the economic climate and also the competitors in the field

6. To avoid communication gap to the maximum between various agencies as the errors caused due to the judgement of effective needs will result in considerable financial loss.

7. To employ the services of the departments such as marketing, R&D (Research and Development), accounts, personnel etc.

8. To not to overlook legislation changes which may sometimes take place and ultimately influence the use of a product.

QUESTIONS WITH ANSWERS

Q. 1.1. Explain why the 'statement of the problem' becomes very important in design process.

Ans. In design process, definition of problem is the most critical step The true problem is not always what it seems to be at first glance. Because time spent here is very small and its importance is overlooked *Time spend by us in defining the problem propetly and then writing a complete problem statement invariably pays off in efficient problem solution*

"Problem definition" is based on identifying the true needs of the user and formulating them in a set of goals for problem solution. The *"problem statement"* expresses as specifically as possible what is intended to be accomplished to achieve goals. *Design specifications are a major component of the problem statement.*

The key role played by a problem statement in the design process is shown in Fig 1.3

The problem statement defines a poorly identified problem area as sharply as possible. Its essential elements are :

- A need statement.
- Definition of terms or conditions.
- Gools, aims and objectives
- Constrants and trade off
- Criteria for evaluating the design.

In view of the above essential elements we find that problem statement is an essential gradient for a good design process.

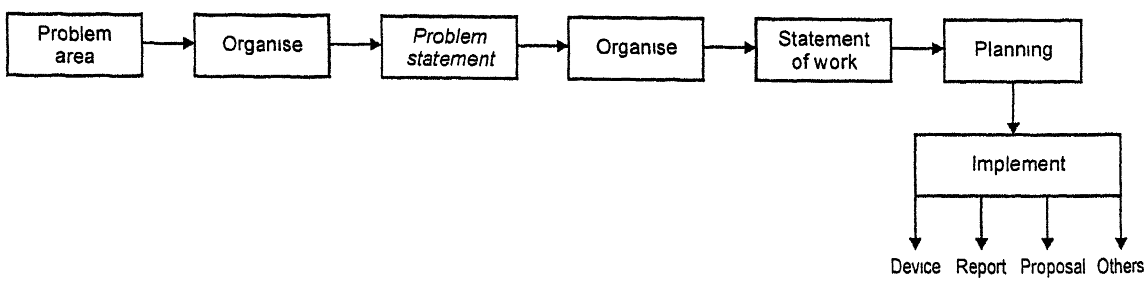


Fig. 1.3. Key role of the problem statement in design process.

Q. 1.2. Explain briefly the following three types of design :

(*i*) Conceptual design.

(*ii*) Creative design.

(*iii*) Redesign.

Ans. For launchıng any new or modified product a design team generally adopt the followıng types of designs .

1 Conceptual desıgn

2 Creatıve desıgn.

3 Redesign

1. Conceptual design. The conceptıal desıgn ıs that part of the desıgn process ın which, by the ıdentıficatıon of the essentıal problems through abstractıons, by the establıshment of functıon structures and by the search for approprıate reductıon prıncıples and their combınatıons, the basıc solutıon path ıs laıd down through the *elaboration of a ıeductıon conc ept*

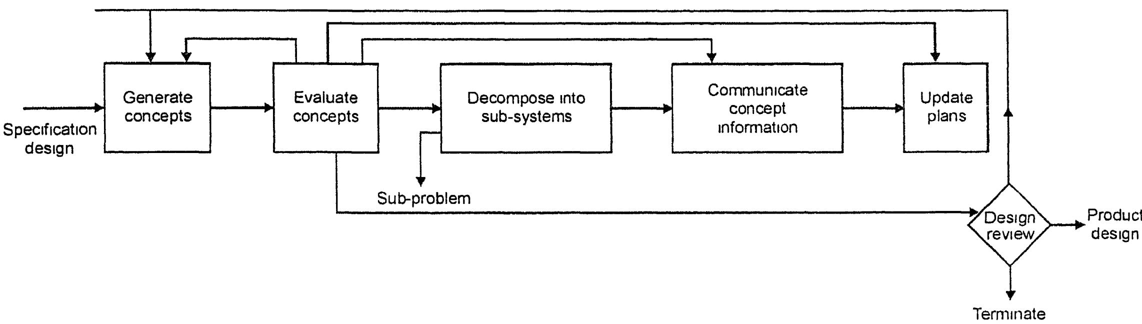


Fıg. 1.4. Conceptual desıgn phase of the desıgn process.

When the concepts are **'generated'**, the *customer's requırements serve as a basıcs for developıng a functıonal model of the product* When the concepts are **evaluated** the *goals are to compare the concepts generated to the requırements developıng durıng specıficatıon development and to select the best concepts for refinement ınto products*

Confirmıng that the proposed product wıll operate as antıcıpated and that, wıth reasonable further development, ıt wıll meet the targets set ıs a *prımary goal ın concept development* Concepts must also be refined enough to evaluate the technologıes needed to realıze them and to some lımıted degree to evaluate theır manufacturabılity

Concepts can be represented ın a rough sketch or flow dıagram, a proof-of-concept prototype, a set of calculatıons an abstractıon of what mıght some day be the product Enough detaıls must be developed to model performance so that the functıonalıty of the ıdea can be ensured

Figure 1.4 shows the conceptıonal desıgn phase of the desıgn process

2. Creative design. The ***creative design*** *ıs breakıng the problem into small pıeces, puttıng these small pıeces together ın a new way and testıng to dıscover the consequences of puttıng the new arrangement ınto practice*

The designer is to develop creatıve methods by usıng good problem-solvıng technıques, to help decompose the problem ın ways that maxımıse the potentıal for understandıng it, for

generating good solutions, for evaluating the solutions, for deciding which solution is the best, and for deciding what to do next

Solution evaluation. People generate ideas but have no ability to evaluate them Evaluation requires two actions — *comparison* and *decision making* Before we make a decision on the ability of an idea to solve a problem, we must compare the performance of the said idea with laws of nature, the capability of the technology, and the requirements of the design problem itself

Following are the *four dimensions of the creative design problem solving team*

(*i*) *First dimension-Problem-solving style.* This indicates that the team-member is reflective is a good listner, thinks and then speaks, and enjoys having time alone to solve problems

(*ii*) *Second dimension.* If reflects whether the individual prefers to work with facts These persons are literal, practical and realistic. They look for relationships between pieces of information and the meaning of information

(*iii*) *Third dimension* It reflects the objectivity with which decisions are made People who are logical, detached and analytical take an objective approach to make decisions

(*iv*) *Fourth dimension* It is the personality of the individual Some people are *decisive* and others are *flexible.* If a member makes decision with a minimum of stress and likes an environment that is ordered, scheduled, controlled, and deliberate, then he or she is decisive If a person goes with flaw, is flexible, adaptive and spontaneous and finds making and sticking with decisions difficult, then the member is considered flexible.

3. Redesign. In industry, most design problems are for the redesign of the existing product. *It is the modification of an existing product to meet new requirements* The redesign effort may require parameter changes, material changes, change in the manufacturing method due to change in the technology etc. Changes may be required to attract new customers Thus the redesign of a product, even a natural one, may require a wide range of design activity

Following are the *guidelines* for a redesign problem :

For a redesign problem-if working with a sample of an existing device, try the following

(*i*) Diassemble the product, one component at a time.

(*ii*) As each component is removed, note what objects — features, components, assemblies, humans or other—it interfaces to and list the flow of materials, energy, and information between them. Each component must conserve energy and materials and be in force equilibrium

(*iii*) For each change in energy, material, or information, draw a function box showing the inputs and outputs This box should also show the components that interact to provide the function.

(*iv*) Develop sub-function ideas by reviewing customer requirements and visualizing the flows

(*v*) Arrange the sub-functions in independent groups. Then arrange them within each group so that the output of one function is the output of the other

(*vi*) Redundant functions must be identified and combined

(*vii*) Functional choices must be identified and either left as an option or a decision made.

(*viii*) Functions not within the system boundary must be eliminated.

Q. 1.3. Explain with example the evaluation of design concept against economic criteria.

Ans. 'Design concept' *signifies the validity of the design idea* The validity comes only after selecting the best solutiton, preparing a suitable model and testing it thoroughly to conclusively establish that all the basic needs for which design was planned are being fully implemented

For calculating the physical realizability of design concept for idea, *"design tree approach"* has been developed by MARPLES It is a *probability study*. Fig 1 5, shows the design tree approach A certain design concept has sub-problems say D_1, D_2, D_3, D_4 The success of these depends upon the success of its sub-problems D_{11}, D_{12}, D_{13}, D_{21}, D_{22}, D_{23}, D_{31}, D_{32}, D_{33}, D_{41}, D_{42}, D_{43},. *From data on probabilities of sub-problems, it is possible to workout whether the design concept will succeed or not*

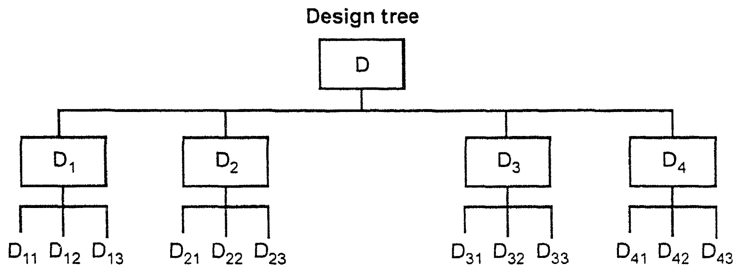


Fig. 1.5 Design tree approach.

An organisation's success or failure may depend on the economic considerations attached at the design phase of the product The designer must therefore take the *following factors into consideration while designing a new product*·

(*i*) Competitive product prices

(*ii*) Percent of the total market for the demand of the product being designed

(*iii*) The size and type of total market

Following are the *principal elements of an item production cost* ·

(*i*) Material cost

(*ii*) Labour cost.

(*iii*) Production overhead cost (machinery, depreciation, indirect labour, fuel and electricity cost, cost of small tools, lubricants etc)

For economic evaluation a job plan is decided for the design concept which may comprise of the following .

- General information of the product design
- Functional consideration
- Creative approaches
- Evaluation of different aspects.
- Investigations of concepts.
- Finalisation of the design concept

Because design concept and the design product has a time gap, certain economic evaluation *formulae* are used to determine the present value of the product which will take shape in due course. Following are the two most commonly used formulae for economic evaluation :

1. Present value — *Single payment*

$$P = P_n (1 + r)^{-n}$$

2. Present value — *Equal payment series*

$$P = I\left[\frac{1-(1-r)^{-n}}{r}\right]$$

where, P = Present value of money,
n = Number of years,
r = Rate of interest compounded annually,
I = Value of each payment deposited at the end of each year, and
P_n = Total amount of money after n years.

Q. 1.4. Give a short overview of modelling simulation and optimisation techniques in engineering design.

Ans. Modelling and simulation.

- A system analyst in simulation is interested in optimising the system, *i.e.*, in finding ways which make the components of a system work together in best possible ways Thus **simulation** *is a tool for analysing and designing systems.*
- Specifically *simulation is used when analytical and numerical methods to find solutions breakdown.* There are many steps in analysing a system. One of the major steps is *to find a solution from the model.* In many cases it is not possible to conduct the experiment, but if we have sufficient information regarding the system, the model can be simulated Thus **modelling** *is the representation of a system or part of a system in physical or mathematical form that is suitable for demonstrating the behaviour of the system.*
- **Simulation** *involves subjecting models to various inputs on environmental conditions to observe how they behave and thus explore the nature of the results that might be obtained from the real-world system.*

The widespread use of the computers has greatly expanded the scope and usefulness of mathematical modelling. The use of numerical methods for solution and the ease with which iterative procedures can test many specific states of the model, have *firmly established computer modelling and simulation as a powerful tool of engineering design.*

- The models are used by engineers for thinking, communications, prediction, control and training. Since many engineereing problems deal with complex situations a model often is an aid to visualizing and thinking about the problem.

Optimisation techniques in engineering design :

- It has been generally observed that for a given objective there can be an infinite number of possible design solutions. In any design problem there are some *practical limitations like, stresses, deflections, vibrations, space occupancy weight etc. These are known as* ***undesirable effects.*** A tolerance limit can always be established for the permissible degree of each undesirable effect. Also there are ***desirable effects like***

power transmission capability, energy absorption capability, length of life etc. Any one of these effects can be the basis upon which an explicit overall object of design is to be obtained.

- Based on the circumstances, it is possible to assign the condition of design to minimise the most significant undesirable effect or maximise the most significant desirable effect. As such an additional design objective is set before hand which results in an explicit design procedure for selecting materials and geometry. This procedure leads to a design which is best possible one from the standpoint of the most significant effect and is known as the *"optimum design"*.
- **Optimum design** *provides most desirable solution.* Basis for optimum design can be any one of the innumerable possibilities, the selection depending upon the relative importance for the particular problem at hand.

Example. A shaft could have optimum designs for the following considerations and solution in each case will be different, *Optimum design for :*

— Minimum cost;
— Minimum weight,
— Minimum torque felt by machine frame,
— Maximum power transmission capability;
— Maximum energy obsorption capability.

The use of approximations may be required to simplify originally available complex equations, or to convert graphical and tabular data to equation form by mathematical approximation techniques.

Q. 1.5. What is the difference between feasible design and optimal design ?

Ans. Feasible design. *"Feasible design" is an effort made to solve the problem* In the conceptual or feasible phase, aim is to initiate the design and establish the line of thinking. This phase consists of one major step where in effort is made to conceive a number of plausible alternate solutions to the problem. The ingenuity and creativity of the designer comes into full play. These *alternate solutions are feasible designs.*

Optimal design. *"Optimal design" means the best of all feasible designs It is carried out by optimization.* The design is an interative process, usually there is more than one solution, thus in engineering design, designer has a situation in which there is a search for the best answer. This is done by optimizatison and the *best design is called "Optimal design"*

Q. 1.6. Explain how will you identify design variables; constraints and objective functions for the design of a helical compression spring. Assume that spring is to be used in a cam-shaft assembly of an internal combustion engine.

Ans. A *cam* is rotating machine element which gives reciprocating or oscillating motion to another element known as *follower.* Cams are widely used for operating the inlet and exhaust valves of internal combustion engines Helical compression spring used for I.C engines should be *open coiled,* the spring wire is coiled in such a way that there is a *large gap between the two consecutive turns, as a result of which the spring can take compression load Helix angle should also be large.* The materials of the springs largely depend upon service for which they

are used. In valve springs rapid continuous loading occurs. These springs are either cold formed or hot formed depending upon size of the wire. Strength of wires varies with size, smaller size wires have greater strength and less ductility.

Following are the design parameters which need to be identified and where valves are to be fixed :

(*i*) Spring materials.

(*ii*) Diameter of the spring wire.

(*iii*) Number of coils.

(*iv*) Diameter of the coil turns.

One physical law which is applicable to this situation relates the *deflection of the spring to the load applied on it through the force constant of the spring. The spring constant depends on all four parameters identified above, we cannot fix the four variables just by considerations of the desired spring constant. The choice to select one solution is made on the basis of some criteria.*

Q. 1.7. Discuss the need of 'optimisation' in engineering design. Also comment whether an 'optimal design' will also be a 'feasible design'.

Ans.

- **Design** ***is an iterative process.*** You start with a poorly defined problem, refine it, develop a model and arrive at solution. Ussually there is more than one solution and the first one is not usually the best Thus in engineering design we have a situation in which there is a search for the best answer. In other words, *optimization is inharent in the design process* . A mathematical theory of optimization has been developed since 1950, and it has gradually been applied to a variety of engineering design situations. The concurrent development of the digital computer, with its inherent ability for rapid numerical calculations and search, has made the utilization of optimization procedures practical in many design situations.
- By the term *optimal designs* we mean the *best of all* ***feasible designs.*** *"Optimisation" is the process of maximising a desired quantity or minimising the undesired one.* Optimization theory is the body of knowledge which contains algorithms which help in achieving the objective function while satisfaying the constraints of resources, time, money and materials. In view of the above discussion we can say that optimal design will probably will also be a feasible design.

Q. 1.8. What do you understand by sensivity analysis and compatibility analysis ?

Ans. Sensitivity analysis. In the preliminmary phase of design, a mathematical model of the design is constructed. The effect of change of each parameter on the decision or response variable is determined. A robust design is one which does not indicate excessive sensitivity to noise factors.

Compatibility analysis. In designing a system it should be verified that various components fit and match well with each other. For *example,* in a pump and electric motor combination, the water horse power (product of total head and discharge) of the pump should match the H.P. of the motor for attaining a high efficiency.

Q. 1.9. Justify the following statement with reasons :
'Modern design problems cannot be handled by traditional methods'.

Ans. In modern times, in order to satisfy customer with choices, a very large variety of designs has to generated. *Traditional designs* are results of *slow evolution.* A closer look at the history of mankind indicates that many products are *the result of a slow process of evolution*

— Take for instance the *plough* which is a basic farm implement for tilling of land. It gradually envolved from its man pulled version to version pulled by bullocks. Later on, oil engines were used for pulling suitably designed blades as in the *power tillers.* Further development of the 'power tiller' is the *'farm tractor'.* A tractor covers much more hectares of land than the power tiller. Further, suitable attachments can convert a tractor to a seeding machine and so forth.

— The development of bicycle from 'crank driven' version to the chain and sprocket wheel version represents design by evolution.

Following are the *"shortcomings" of slow evolutionary design* which makes it unsuitable for modern times :

1. Unsuitability for mass production
2. Difficulty in modification
3. Inability to tap new technologies.

Q. 1.10. Discuss the divergence, transformatiton and convergence phases in the design of a new product.

Ans. Divergence, transformation and convergence phases in the design of a new product are discussed below :

Divergence phase. This phase has two tasks to perform 'First', *establishing a preliminary statement of the need* and 'second', analysing *that need to determine its exact nature*

Transformatiton phase. This phase consists of one major step wherein effort is made to conceive a number of feasible alternative solutions to the problem. In this step the creation of the designer comes into full play.

Convergence phase. This phase starts with narrowing down the field of plausible solution to most promising ones on the basis of physical realisability, utitlity and financial feasibility. *After this phase, preliminary design and detailed design are carried out*

Q. 1.11. What is design optimisation ? Illustrate your answer with examples.

Ans. Optimisatiton theory in general terms, is a body of mathematical results and numerical methods for finding and identifying the best alternative from a collection of alternatives without having to enumerate and evaluate explicitly all possible alternatives.

Optimisatiton can be explained with ***examples*** as follows :

1. It is desired to insulate a building to save fuel. One component of the cost is *directly* proportional to the insulation thickness (x) which represents the cost of insulating material. The second component is the increase of fuel needed which varies *inversely* with insulation thickness (x).

$$C = \frac{K_1}{x} + K_2 x$$

For minimum cost of fuel plus insulation

$$\frac{\partial C}{\partial x} = -\frac{K_1}{x^2} + K_2 \text{ or } \quad x = \sqrt{\frac{K_1}{K_2}}$$

2. Designing multi-story construction for stability and freedom from ill effects of earthquake
3. Designing autotmobiles for dynamic stability while turning along sharp curves

Q. 1.12. What are the three different stages in the design process ? Explain with an example.

Ans. The three stages in the design process are .

1. Feasibility stage.
2. Preliminary design stage.
3. Detailed design stage.

The above design stages can be illustrated through an example for the pump for handling fluid containing suspended matter of say 20 mm particle size.

• **Feasibility stage.** In the feasibility phase the following points are to be taken care of: (*i*) Physical realisability; (*ii*) Economic worth; (*iii*) Financial feasibility

— Since the pump has to handle a fluid other than water, it has to be verified that the material of the impeller, volute casing, sealing material etc. should withstand the aggressive effect of the fluid. In *physical realisability* it should be verified that the materials and processes are compatible and that they meet the functional requirements.

— *Economic worth* estimate verifies that the customer should be willing to pay the price which for a profitable product should be more than the cost of production.

— *Financial feasibility* verifies that if a plant is to be set up for manufacture of pumps, the present worth of cash flow during the life cycle of the pump should exceed the total initial investment.

• **Preliminary design stage.** This phase *atempts to develop an optional design. For example,* the profile of vanes and their angle should be so designed that the hydraulic design of the impeller is according to principles of fluid mechanics; likewise the volute casing should be so designed that the velocity head developed by the impeller is converted to a pressure head. Thus for the given H.P. and r.p.m. input by the motor the desired lift is achieved.

• **Detailed design phase.** After the derivation of the 'Optional design' the various drawings of components, sub-assembly and finally assembly are prepared All the tolerances, clearances and fits are specified in the drawings.

In the detailed design phase a prototype is developed to verify that the design meets the functitonal and efficiency requirements

Q. 1.13. Carry out the need analysis for designing a plastic toy rocket for children in the age group 8-12 years.

Ans. It is the *need* with which the problem of defining design problem starts, the need refers to (customer's expectations) .

— What does the custotmer expect from the product ?

— How much he is willing to pay for it ?
— What functions the product is supposed to do ?
— How pleasing to the eye is the product ?
— What is the reliability and durability of the product ?

From the point of view of the designer it is important how he is able to convert the customer's need into technological specifications. Thus a *need analysis for a product should result in product specifications at least at a conceptual level.*

In case of a 'Toy rocket' for a child the customary need can be translated into concept development as Table 1.1.

TABLE 1.1
Need analysis for a plastic toy rocket

S.No.	*Need/Function*	*Design feature*	*Hardware*
1.	*Ability to fly*	• Aerodynamic shape. • The toy rocket should have energy source to propel a protter through tiny electric motor	• Plastic moulded shape • Battery/Cell to drive a small motor to revolve propeller.
2.	*Durability*	• Impact resistant material	• Unbreakable plastic material.
3	*Aesthetics*	• Attractive colour. • Blinking lights to be provided.	• Pleasant looking colour.
4	*Safety need*	• Avoidance of sharp corners.	• Propeller chamfers and radius to be provided on mould.
5	*Low cost*	• Cost being one of the specifications, the cost not to exceed Rs. 700/-	• Use of inexpensive materials.

Q. 1.14. Explain different characteristic features of slow evolutionary process of design.

Ans. Design by evolution is typified by very gradual improvements in the design of a product. An example of evolutionary process of design is the evolutiton of plough for tilling of land evolving to the power tiller and then to the form tractor.

Following are the *characteristics of evolutionary design* :

1. Evolution process is marked by small changes and is not the result of tapping new technology. It does not even use sophisticated design tools such as CAD.

2. An evolved design is shaped by demands of time and not the result of any spark of genius.

3. An evolved design is crude until it is in final refined stage. It is suitable at village level but unsuitable for sophisticated applications.

Q. 1.15. What makes the design process tortuous ? Explain.

Ans. The design process is an iterative process comprising of information input, design process, decision-making and output as shown in Fig. 1.6. From the figure it may be observed

that at each step there is *vertical downward movement* whereas within a step there is *laterol flow along* the flowchart. Thus a horizontal flow combined with a vertical movement between steps lends the design process a *fortuous or spentine path.* For example, in Fig. 1.6. Process step-1 could be *"Need analysis"*; Step-2 could be *"System identification"* and Step-3 could be *"Design concepts"* whereas specific information (1) would be *"market information"* and information (2) would be *"Technical information"*.

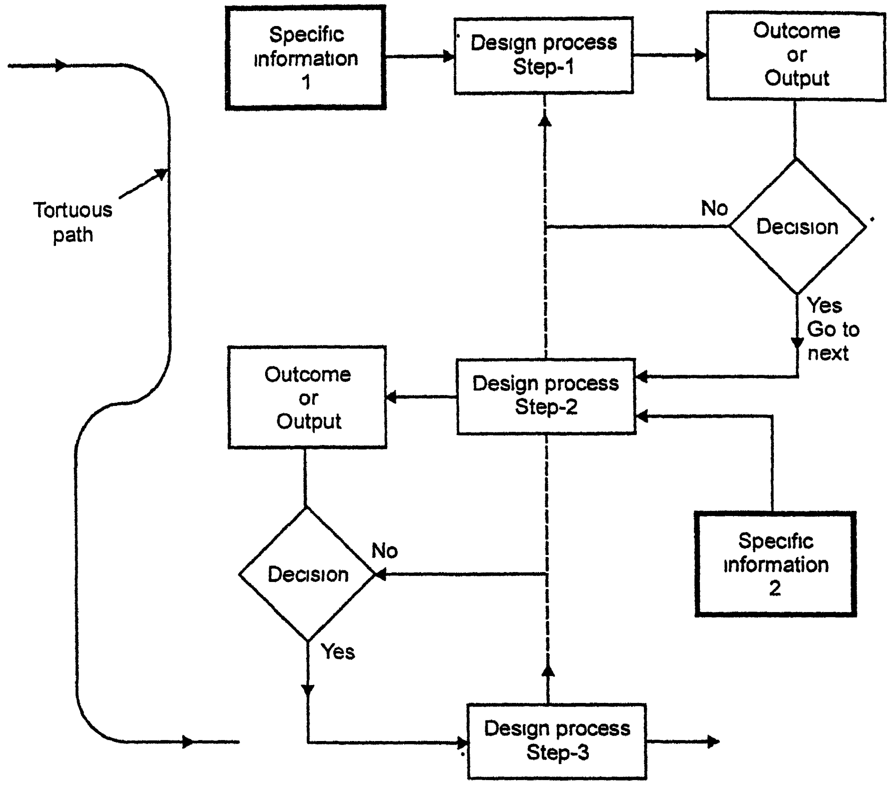


Fig. 1.6.

Q. 1.16. Enumerate the steps in engineering design process and explain.

Ans. The various *steps* in engineering design process are as follows :

1. Investigation of customer needs.
2. Conceptualization.
3. Preliminary refinement.
4. Further refinement and final concept selection.
5. Control drawings.
6. Co-ordination with engineering, manufacturing, and vendors.

1. Investigation of customer needs. The product development team begins by documenting customer needs "Identifying Customer Needs". Since industrial designers are skilled at recognising issues involving user interactions, ID involvement is crucial in the needs process.

- For *example*, in researching customer needs for a new medical instrument, the team would study an operating room, interview physicians, and conduct focus groups. While involvement of marketing, engineering, and ID certainly leads to a common, comprehensive understanding of customer needs for the whole team, it particularly allows the industrial designer to gain an *intimate understanding of the interactions between the user and the product.*

2. **Conceptualization.** Once the customer needs and constraints are understood, the industrial designers help the team *to conceptualize the product.* During the concept generation stage engineers naturally focus their attention upon finding solutions to the technical subfunctions of the product. At this time, the industrial designers concentrate upon creating the product's form and user interfaces. Industrial designers make simple sketches, known as *thumbnail sketches*, of each concept These sketches are a fast and inexpensive medium for expressing ideas and evaluating possibilities.

3. **Preliminary refinement.** In the preliminary refinement phase, industrial designers build models of the most promising concepts. *Soft models* are typically made in full scale using foam or foam-core board. They are the second fastest method — only slightly slower than sketches — used to evaluate concepts.

Although very rough, these models are invaluable because they allow the development team to express and visualize product concepts in three dimensions. Through the process of touching, feeling, and modifying the models created, industrial designers, engineers, marketing personnel, and (at times) potential customers evaluate each concept Typically, designer will build as many models as possible depending on time and financial constraints. Concepts that are particularly difficult to visualize require more models than to simpler ones.

4. **Further refinement and final concept selection.** At this stage, industrial designers often revert from soft models and sketches to hard models and information-intensive drawings known as *renderings* Renderings show the details of the design and often depict the product in use. Drawn in two or three dimensions, they convey a great deal of information about the product. Renderings are often used for colour studies and for testing customer's reception to the proposed product's features and functionality.

The final refinement step before selecting a concept is to create *hard models* alluded to previously. These models are still technically non-functional yet are close replicas of the final design. They are made from wood, dense foam, plastic, or metal; are painted and textured, and have some "working" features such as bottons that push or sliders that move. Because a hard model can cost thousands of dollars, a product development team usually has the budget to make only a few.

5. **Control drawings.** Industrial designers complete their development process by making control drawings of the final concept. Control drawings document functionality, features, sizes, colours, surface finishes, and key dimensions. Although they are not detailed part drawing (known as engineering drawings), they can be used to fabricate final design models and other design models and other prototypes.

6. **Coordination with engineering, manufacturing and external vendors.** The industrial

designers must continue to work closely with engineering and manufacturing personnel throughout the subsequent product development process. Some companies now even use industrial design consulting firms that offer quite comprehensive engineering services, including detail design and the selection and management of outside vendors of materials, tooling, or components, as well as vendors to perform the final assembly of the product.

- **The impact of Computer-based tools on the ID process.** In recent years, new computer-aided industrial design (CAID) tools have begun to have a significant impact on industrial designers and their work. Using CAID tools, industrial designers can generate three-dimensional designs on a computer screen and rapidly modify them. In this manner, ID can potentially generate a greater number of detail concepts more quickly, which may lead to more innovative design solutions.

Q. 1.17. What is a feasible design ? What is an optimal design ? What different methods can be followed to realize an optimal design ?

Ans. A **feasible design** *should satisfy the criteria of physical realisability and should be economically worthwhile and should be financially viable.* Physical realisability means that the design idea should be capable of being translated in material form. Economic worth means that the society should be willing to pay equal 10 or more than its cost. Financial feasibility look upon a product as a project and verifies that the net present value of all cash flows during product life cycle exceed initial investment.

An **optimal design** is *one which is the best out of a number of feasible designs.*

Siddall, who has reviewed the development of optimal design methods gives the following insightful description of *optimization methods :*

1. Optimization by evolution. There is a close and parallel link between technological evolutioin and biological evolution. Most designs in the past have been optimized by an attempt to improve upon an existing similar design. Survival of the resulting variations depends on the natural selection of user acceptance.

2. Optimization by intuition. The art of engineering is the ability to make good decisions without being able to formulate a justification. ***Intuition** is knowing that to do without knowing why one does it.* The gift of intuition seems to be closely related to the unconsious mind. The history of technology is full of examples of engineers who used intuition to make major advances. Although the knowledge and tools available today are so much more powerful, there is no question that intuition continues to play an important role in technological development.

3. Optimization by trial-and-error modelling. This refers to the usual situation in modern engineering design where it is recognized that the first feasible design is not necessarily the best. Therefore, the design model is exercised for a few iterations in the hope of finding an improved design. However, this mode of operation is *not true optimization.* Some refer to satisfying, as opposed to optimizing to mean a technically economical. Such a design *should not be called an optimal design.*

4. Optimization by numerical algoritha. This is the area of current active development in which mathematically based strategies are used to search for an optimum.

Q. 1.18. What are the factors which affect process selection ?

Ans. A process is necessary in order to shape, form, condition and join materials and components, with the help of machines and labour, in order to *convert raw material into a finished product.* One should select the most economical process and sequence, that satisfies the product specifications.

The selection of process depends upon the following *factors :*

1. Current production commitments.
2. Delivery date.
3. Quantity to be produced
4. Quality standards.

Q. 1.19. What steps are involved in the process and equipment selection procedure ?

Ans. Following are the formal steps of the process and equipment selection procedure .

1. To develop a general statement of the manufacturing operations to be performed
2. To establish a provisional process to provide each individual feature identified by the product designer.
3. To develop a list of process alternatives, particularly for these areas where detailed analysis of the preliminary processing had shown high cost, questionable performance, or places where the confidence level of achieving the requirements of the individual operator is judged to be marginal.
4. To finally select the process (compromised position), which optitmizes all the elements of cost, quality, flexibility and inherent risk.
   — All enginering management and manufacturing considerations being equal, *production processes will be chosen on the basis of the most favourable return on investment or other financial criteria.*
5. To communicate (about the process selection) to the product engineering, industrial engineering, plant and maintenance engineering, industrial relations and finance departments. This will provide coordination and communication among all concerned which is essential for the successful adaptation of new technology to existitng plant and staff.
6. To perform detailed processing.

Q. 20. What are the methods currently adopted for design process using advanced technology ?

Ans. For design process, Computer Aided Design (CAD) is adopted. It covers several automated technologies in addition to design geometric specifications of a part. CAD includes computer aided engineering, used to evaluate and conduct engineering analysis on a part. CAD also includes two technologies associated with manufacturing process design.

CAD can be used to design numerically controlled part programs, which give instructions to computer controlled tools and to design the use and sequence of machine centres.

CAD allows the designer to conceptualize objects more easily without having to make costly illustration models or prototypes.

The design process in CAD system consists of the following *four stages :*

(*i*) Geometric modelling (wire frame, surface or solid model).

(*ii*) Design analysis optimizatiton.

(*iii*) Design review and evaluation.

(*iv*) Documentation and drafting.

Q. 1.21. Discuss the meanings of conceptual design, creative design, adaptive design and variant design.

Ans. 1. Conceptual design. It is that part of design process in which, by identification of essential problems *through abstraction,* by the establishment of essential problems *through abstractison,* by the establishment of function structures and by the search for appropriate solution principles and their combination the basic solution path is laid down through the claboration of a solution concept.

2. Creative design. When a totally new product is to be designed the most demanding design effort and creativity is needed. This type of design is creative design.

- *Creative design means a design produced or created by branstorming or by artistisho mind.*

3. Adaptive design. This type of design requires only *minor modification* usually in size alone. The level of creativity needed is negligible because adaptation of existing design is essential. Some authors such as Martin S. Ray call it *Adaptive design* even if changes are more but original design concept is the same.

4. Variant design. This design approach is followed by companies who wish to serve product variety to satisfy varying customer tastes and which involves *varying the size of arrangement of certain aspects of the chosen system, the functions and solution principle remaining unchanged.*

Example. Bajaj 15 and Bajaj Chetak are variant designs.

Q. 22. Discuss the importance of 'Probabilistic design' over 'Conventional method of design'.

Ans.

- Probabilistic design methods *involve with more versatile mathematical systems* which take into consideration both mean value and variance for the parameters (instead of a single value employed in conventional methods). There has been seen marked improved design by employing a *rational approach (probabilistic consideration) which is adequately equipped in the form of statistical algebra.*
- In the conventional methods, it has been observed that the complexity of designing is overcome by using a tentative solution as a quick means of exploring both aspects which design is to fit and the relationship between components.

Q. 1.23. Discuss regarding the theory of critical decision making in design.

Ans. The theory of critical decision making in design was developed by design philosopher Morris Asimow. According to him if (L) is the level of confidence that in a design can be realised subject to Budgetary constant and if (G) is the Gain in monetary terms, the overall gain under the above conditions is given by,

$$\text{Overall Gain} = [(L)\,(G) - (1 - L)P]$$

where, P = Penalty due to design failure, and

$(1 - L)$ = The probability of failure.

The formula for calculating level of confidence L is given by :

$$L = 10 \log_{10}\left(\frac{R}{1-R}\right)$$

where, R is the physical realisability of the product design. L has to be converted from decibel value to probability value.

Q. 1.24. List the reasons why methods of Robust design can aid in successful commercialisation of products and processes.

Ans. Robust design *means that the product is designed so that small variations in production or assembly do not adversely affect the product.*

Following are the reasons which aid in successful commercialisation of products and processes applying robust design.

1. Robust design *reduces* production cost of product and process both.
2. Robust design *reduces* research and development cost.
3. Robust design *allows continuous improvement* in quality of product, which is necessary to stay in business.
4. Robust design can be *produced to requirements even with unfavourable conditions* in the production.
5. Statistically planned experiments can efficiently and reliably identify the setting of product and process parameters that *reduce performance variation.*
6. Variation in product or process performance can be reduced by robust design using non-linear effects of the product or process parameters.
7. Since in robust design, inspecting, appraising and evaluating the quality of products go out of line, a large sum of money spent for doing these is *saved.*

Q. 1.25. What do you understand by the term 'Creativity'? What are its requirements?

Ans.

- **Creativity** *is a new combination of thoughts or things.* It involves the combining and recombining past experience into new pattern that better serve the human needs. Creativity is the ability to bring somethting new into existence. *Originality or novelty is the main essence of creativity.*
- **Requirements of creativity :**
  1. *Desire to be creative.*
  2. Having a need and confidence in our ability to solve that need by working on it.
  3. Love of adventure.
  4. Ability to improvise.
  5. Determination.
  6. Intelligent scepticism.
  7. Ability to reason.
  8. Persistent concentratiton.
  9. Combinatitonal conception.

Q. 1.26. Explain the meaning of (*i*) Conceptual design; (*ii*) Functional design; (*iii*) Production design.

Ans. 1. Conceptual design. It is the earliest form of design generated to *start the design process which can be modified in later stages.* Here problems are abstracted by establishing and making a concept design of product.

2. Functional design. In such a design, the *functions or performance specifications of any product are assigned on which product has to work* For *example*, an electric heater. In functional design of heater, it is assigned how it has to work, appearance and its utility functions and materials to be used for manufacture are decided.

3. Production design (*process design*). In this stage of design process a manufacturing process by which product is to be made, its assembly part, its storage in warehouses prior to sale and distribution aspects are decided. For example, electric heater, how it shall be manufactured and type of material for manufacture, its storage before sales are decided or thought in production design phase.

Q. 1.27. What is meant by optimisation? Why there is necessity of optimisation in engineering design ? Differentiate between feasible design and optimal design.

Ans. Optimisation *is the process of maximizing the desired quantity and minimizing the undesired one with the help of mathematics.* With the help of optimization we can reach to optimal design which is finally accepted for manufacturing.

A designer while designing an engineering product faces a situation in which there is a search for the best answer, for this optimization is used. Thus we find that *optimization is inherent in design process.*

In industrial design activity a native optimal design is achieved by comparing a few (upto ten) alternative design solutions created by using a prior problem knowledge. In such an activity the feasibility of each design solution is first investigated. Thereafter an estimate of the underlying objective (cost; profit etc.) of each design solution is computed and the best design solution is adopted.

Feasible design. *"Feasible design" is an effort made to solve the problem in the conceptual or feasible design phase, aim to initiate the design and establish the line of thinking.* This phase consists of one major step where in effort is made to concieve a number of plausible afternate solutions to the problem. The ingenuity and creativity of the designer come into full play. *These alternate solution are feasible designs.*

Optimal design. Optimal design means *best of all feasible* designs. This type of design is carried out by the optimisation. The design is an *iterative process,* usually there is more than one solution in which there is a search for the best answer. This is done by optimisation and the best design is called *optimal design.*

Q. 1.28. Define creative design routes. What are the stages of these routes ?

Ans. Creativity is a subject of research by psychologists. It is true that some persons are more creative than others. They can generate more useful ideas than others. However, even an average person can be creative if he cultivates and sharpens his wits. A positive and sunny frame of mind is a must.

Alger and Hayes have given the following shapes of creative design:

1. Establishment of *familiarity with the problem.*
2. *Soaking the mind with the problem.*
3 *Try various combinations.*
4. Permitting *'Incubation'* of the problem in the conscious and subconscious mind
5 *Illumination* is the stage when a solution is obtained.
6 'Recording' the solution and further refinment of solution.

Q. 1.29. What are the desirable qualities of a creative designer?

Ans. A creative designer should possess the followings *qualities :*

1. Imaginative and apply fantasy
2. Free from fixity of mind.
3. Open and perceptive.
4. Enthusiastic with a positive frame of mind.

Q. 1.30. Explain need analysis taking some specific product.

Ans. For a design engineer, the information about needs from various phases is of crucial importance. Keeping in line with the business policy of production concern, a need can be analyzed thoroughly by surveying the past, present and future market concentrating on the needs of the end user directly as follows:

— Real expectations or actual needs of the user's, and in case of redesign user's complaints;
— Extent of demand;
— How the needs are being satisfied as present;
— Extent of competition;
— Price which the user would be capable and using to pay

The various persons involved in the product design, *viz.*, manufacturer and distributor etc. have different needs from their own point of view and very often of conflicting nature. The designer has to analyse, understand and weigh them properly. The distributor wants the product with good appeal, with no service problem, safely transported and with lots of profit The manufacturer wants them easily made by low cost labour and easily procured materials with no seasonality and with high demand

The *main purposes of the need analysis are.*

1. *Satisfaction to customer,* which is achieved when the following conditioned are fulfilled.
   - Product should possess high degree of accuracy.
   - It should function correctly.
   - It should operate easily and smoothly.
2. Manufactured process adopted is *easy and smooth.*
3. *Suitable to manufacture with use of standard components.*

In case of manufactured products, the general characteristics percieved by the consumer must be translated into engineering specifications for every part or sub-assembly so that there will be no ambiguity about their processing at specific work stations.

Let us consider the product **electric iron.** The following *requirements need be considered:*

- It should work on 220V.
- Its element should be of proper voltage and well insulated.
- It should be light in weight.
- Its base plate should be rust proof.
- It should have temperature control.
- It should have current flow indicator.
- Its junction box should be steady and rigid.
- Its should be insulating towards electric flow and heat flow.
- Its extension wire should be flexible and durable.
- The weight or pressure plate should be of cheap material.
- The plug with wire to be of three-pin and of good material to withstand high temprature (say 200°C).
- The components should be accessible and replaceable etc.

All these requirements so to say needs are to be considerd and based on the followings:

— Selection of materials;

— Selection of method of manufacture;

— Selection of method of assembly;

— Selection of method of testing;

— Designing packing box etc.

After considering all the needs it will be possible *to design the product is a systematic manner with economy, ornamental appearances and durability of the product in mind.*

Q. 1.31. Briefly discuss the concept of creativity as applicable for solving design problems.

Ans. Successful engineering design depends on modes of thinking distinctly different from those we use in everyday life. Existence of these differences, makes design an intellectually demanding activity. For a good and successful design we have to apply creativity because a creative thinker is distinguished by his ability to synthesise new combination of ideas and concepts into meaningful and useful forms. *Engineering creativity is more akin to inventiveness than research.*

Design is commonly thought of as a creative process, involving the use of imagination and lateral thinking to create new and different products, but this statement is misleading as although creativity and original ideas are often called in for design products, much design work is highly original is nature. But majority of engineering design activity falls within the scope of variant design which means variations in size or arrangement of chosen system.

Q. 1.32. What is need analysis ? Explain with the help of an example.

Ans. The need for a particular product is *identified through market research and market survey.*

The need is stated in the form of a *'Primitive Need Statement'*. This statement does not

directly state the detailed specifications of the product. To generate more ideas and stimulate ideation process, an indirect need statement is made.

Once the designer is agreed on the preliminary need statement that he has settled on the essential nature of the problem the next step is *to analyse the need.*

For analysing the need the following *four major factors* should be considered :

(*i*) Required specifications.
(*ii*) Standard of performance.
(*iii*) Resources.
(*iv*) Environmental factors.

— *Specifications* refer to these standards against which the competing design can be judged.
— The designer should also have knowledge of the *resources* available for converting design into the physical realities.
— The designer has also to think of the *operating environment* and the *environment which can adversely effect the operation of the product*

- **Example.** The *'Need Statement'* for electronic fire alarm could be a gadget to sense the temperature of the room in excess of say 70°C and warn the inhabitants of such an occurrence.

Q. 1.33. Discuss creativity and creative design.

Ans.
- The *design by evolution* in the modern world is totally *obsolete.* It has given place *to design by innovation and "creativity".* This method follows the application of scientific discoveries and technological advancement made from time-to-time, technical rule is very high in this method.
- *Pre-requisite of* **creative design** are :
  (*i*) Qualities like sense.
  (*ii*) Ambition to solve problem.
  (*iii*) Determination to obtain result.
  (*iv*) Enthusiasm.
  (*v*) Dedication
  (*vi*) Devotion
  (*vii*) Passions.
  (*viii*) Clear and powerful urge to achieve the desired goal.

'Creative designs' improve the quality and efficiency of traditional products.

'Creative design approach' is essentially a problem solving approach with the following *steps :*

1. Familiarity with the problem.
2. Soaking the brain with the problem.
3 Deliberate doodling.
4 Incubation.
5. Illumination.

6. Listing the solution.
7. Carrying out detailed design.

Q. 1.34. Discuss briefly what you understand by probablistic design ?

Ans. In practical situation the external load acting on machine parts is subject to variation. Material property, *e g.*, strength also is a random variable. For a safe design this is to be accounted. *Probablistic design takes care of these variations.*

Q. 1.35. What are the common features and differences between creative design activities and engineering design activities ?

Ans. *'Engineering design'* comprises the following *phases :*

1. Conceptinal design phase or feasibility phase. In this phase the feasible designs are *proposed by using creativity techniques* such as 'Brainstorming', IADA (Association of Interaconnected Decision Areas), Synetics etc. Alternative proposals are compared from the point of view of physical realisability, economic worth and financial feasibility

2. Preliminary design phase. This design phase is concerned with *testing of design* from the point of view of optimality, robustness, stability and sensitivity.

3. Final phase. In the final phase, *detailed drawings of parts, components, sub-assemblies and assembly* are arrived at. Various tolerances, clearances, surface finish etc. are specified.

From the above, it will be seen that creative design is present in phase-1 of Engg. design activities. Creativity routes are practiced by following the following sequence (Alger and Hayes) ·

1. *Preparation* ..... Needs analysis and collection of information.
2. *Concentration* ..... Digestion of all aspects of the problem.
3. *Incubation* ..... Relaxation away from the problem for sometime.
4. *Illumination* ... A rush of insight, relief and understanding of the solution.
5. *Verification* ..... Testing and Inspection, completing of details.

Fig. 1.7. shows the relovationship between *'Engineering design'* and *'Creative design'* Maximum creativity is needed in feasibility or concept design phase, though it is also needed in the later phases to some extent.

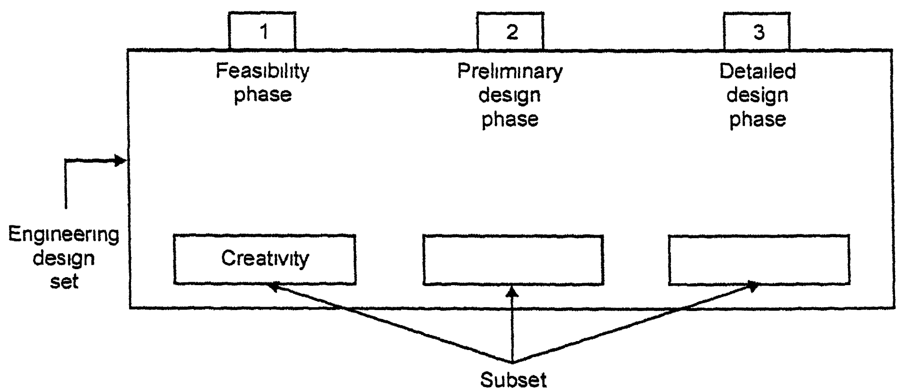


Fig. 1.7. Relationship between 'Engineering design' and 'Creative design'.

Q. 1.36. How can you explain the term 'Design'? Explain the process of mechanical design. Discuss the role of creativity in the design process.

Ans. • **Design.** Design *is concerned with suggesting ways to put together man made things to satisfy human needs in an optimum fashion subject to constaints.* Design being practical in nature must be concerned with what is *feasible. Considerations of physical realisability, economic worth and financial feasibility are the necessary requirements at the concept phase of design'* Later phases are concerned with *optimisation* and *detailing.*

Following are the *various phases of a design process :*

Phase-1 : Specificatiton development/planning.

Phase-2 : Conceptual design.

Phase-3 : Product design.

Phase-4 : Production

Phase-5 : Service.

Phase-6 : Product retirement.

We shall emphasise here the first three phases as they focus on the design of the product.

Phase-1 : Specification development/planning. The objective of this phase is to develop a clear statement of the product requirements in terms of performance, time available, money to be spent, and other specifications. Everythting downstream of this phase depends on the results developed here. Sometimes this phase is also called the *pre-concept phase* in order to emphasize the need to fully understand the problem, prior to developing solution concepts.

Phase-2 : Conceptual design. During this phase a rough idea is developed of how the product will function and how it will look like. *Conceptual designs are typically represented by rough sketches and notes.* Traditionally, this phase of the design process has been the least managed, the least documented, and the least understood. Designer tends to quickly sketch a conceptual design and then spend too much time in product design trying to make the concept to work.

Phase-3 : Product design: This phase is the *most time-consuming phase* of the design process. It *begins with a concept and ends with a ready-to-manufacture product.* Primary among the many considerations in this phase is the concurrent design of the product and the manufacturing process. Traditionally, design engineers completed their work and passed their drawings and notes to the manufacturing engineers, they then decided how to manufacture the product. There was little communication between the design and the manufacturing engineers. This proved to be poor practice. The designer, with limited knowledge of manufacturing processes, would often generate products that were difficult and expensive to produce; the manufacturing engineer would then alter the components for easier manufacture and assembly, with no appreciation for the impact of these changes on the operation of the product.

The weakness in this approach has *led to concurrent design of the product and production, a philosophy that perceives the design process as a team effort.*

Creativity. Design as a problem solving process demands creativity from the designer. We are all used to solving problems. When confronted by a need or a desire, we use whatever

information we know or can easily find to help us to understand the problem and generate a potential solution On the basis of our understanding of the problem and the potential solutions, we evalute the solutions by comparing the alternative and deciding which is the best By doing so, we take *four basic actions*

1 Establish need or realize that there is a problem to be solved
2 Understand the problem.
3 Generate potential solutions for it. Creativity is the ability to generate multitple ideas which is very essential in this stage.
4. Evaluate the solutions by comparing the potential solutions and deciding the best one.

   Additionally, if we want to communicate the result of our deliberations to anyone else or record it for later reference, then a *fifth action* is also needed, *i.e.*,

5 Document the work.

Q. 1.37. Give one need statement for each of the following :

(*i*) Bicycle; (*ii*) Voltage stabilizer; (*iii*) Personal computer.

Ans. (*i*) **Bicycle.** Manually operated vehicle for light weight transportation over short distances or more speed than a man can walk.

(*ii*) **Voltage stabilizer.** Equipment for supplying constant voltage supply with a given range of input.

(*iii*) **Personal computer.** Equipment storage and display of various data files with computation and print out facility.

Q. 1.38. Explain why the step 'Defining the problem' is considered as the most critical step in the design process.

Ans. *Every design problem begins with the recognition of problem or need.* In all design situations, the first task of the designer is to determine what exactly is needed or problem is. This *identification of the problem or need,* simple as it may appear is *crucial first step in the design process and one which is the tripping point for the many projects.* Quite often the designer and sponsors of the design identify the wrong need and take up a wrong problem to handle. It frequentlty happens that a designer starts thinking of the solutions even before he has clearly identified the need and thus he is foredoomed to take the wrong track. His erroneous definition of the problem, dictated by the broad pattern of the solution that he has preconceived, forces him to seek solutions of the sub-problems which result from the general pattern he has assumed And these may not be at all easy to solve. In fact, these sub-problems may be bypassed altogether if he realises that the sub-problems are not inherent to the actual design goal but are byproduct of the broad pattern of the solution he imposed because of his faulty definition of the problem.

Q. 1.39. What is the role of need analysis in the design process ?

Ans. After the designer is agreed on the preliminary need statement that is, he has settled on the essential nature of the problem, the next step is to analyse the need to obtain as complete a definition of it as possible. There are four aspects in obtaining this definition, namely, (*i*) *Specifications,* (*ii*) *Standard of performance,* (*iii*) *Resources,* (*iv*) *Environmental factors.*

- *Specifications* refer to the normal function requirements of a design which every design concept must meet, and *"standard of performance"* refer to those standards which the competing designs can be judged. Thus the requirement that a bicycle must be able to carry a load man weighing 100 kg and in addition a luggage weighing 30 kg could be a specification, the requirement that it should be durable would be a standard of performance.
- The designer must also have a good knowledge of the resources available to him for designing and for converting the designs into their physical realities. *"Resources"* can be in terms of materials, machines, skills and processes available with the designer, the factory where the product will be made, and also, the end user of the product
- Every product and system operate under factors and conditions that are largely imposed by the operating environment and that may adversely affect its performance. If we term such factors loosely as *"environmental factors"* then these can be treated as unfavourable, though inevitable inputs into the product or system The design should be of such unfavourable factors. A designer must try and determine the nature and levels of such factors at the need analysis stage, that is, before he takes up the actual designing.

Q. 1.40. What are the characteristic features of system design, assembly/sub-assembly design and component design. Explain them briefly.

Ans. The characteristic features of system design, assembly/sub-assembly design and component design are :

System design : (*i*) Reliability;
(*ii*) Maintainability;
(*iii*) Synchronization of different assemblies;
(*iv*) Safety.

Assembly/sub-assembly design : (*i*) Reliability;
(*ii*) Maintainability,
(*iii*) Computability;
(*iv*) Interchangeability.
(*v*) Safety.

Component design : (*i*) Reliability;
(*ii*) Interchangeability;
(*iii*) Standardisation;
(*iv*) Computability;
(*v*) Maintainability;
(*vi*) Safety.

- **Reliability.** The probability that a component part, equipment or system will satisfactorily perform in intended function under given circumstances, such as environmental conditions limitation as to operating time, and frequency and thoroughness of maintenance. Reliability should be designed and defected deface

tested out. *Reliability of an item is the probability that it will perform a required function under specified condition for a stated period of time.*

- **Maintainability.** A system design should incorporate all safety features and be equipped with assembly and access techniques that offer minimum interference to the operator, and should be assembled by an organised team.
- **Synchronization.** A rotating AC machine turning with no mechanical load, the process of maintaining one operation in step with another, the example is Electrical Clock whose motor rotates at some integral multiple or submultiple of the speed of the alternator in the power station.
- **Safety.** An empirical number by which the strength of a material is divided to obtain a conservative design stress. A safety factor is used because of uncertainties in operating condition that may be encountered, non-uniformities in material, effects of aging such as corrosion and strains introduced inadvertently during fabrication and transportation and because of the seriousness of failure.
- **Compatibility.** Different components and sub-assemblies should be compatible to each other.
- **Interchangeability.** Geometric analysis of the product of our investigation into factors making up the structure of geometrical analysis to indicate the logical procedure of thinking which materialised the preparation of manufacturing drawing.
- **Standardization.** Procedures to investigate the selection of different ranges of type and sizes for manufacturer trying to assess probable customer demand. The desirability of wide range of choice has to be optimised in terms of the increase in manufacturing cost and stock holding. The basic function is to provide instruction on what should be used and how particular operating or environmental situation will be dealt with. They will indicate when existing codes of practice are to be implemented.

Q. 1.41. List four design ideas which can be used to reduce atmospheric pollution caused by the exhaust of several types of vehicles on the road.

Ans. Following are the *four design ideas* which can be used to reduce atmospheric pollution caused by the exhaust of several types of vehicles on the road :

1. Better engine design. Petrol consists of a mixture of various hydrocarbons. If we could get perfect combustion then exhaust would consists only of CO_2 and water vapour plus air that did not enter in to the combustion process, however, for several reasons combustion is incomplete and hence we get carbon monoxide, a deadly poisonous gas and unburnt hydrocarbons in exhaust, so exhaust omissions are greatly affected by incomplete combustion and pollution can be reduced by improving combustion process in vehicles by *better engine design.*

2. Use of linear Air-fuel ratio. The carburettor may be modified to provide relatively lean and stable air fuel mixtures during idling and cruise operation. Fuel distribution is improved by better manifold design, inlet air heating, raising of coolant temperature. It reduces exhaust pollution.

3. Selection of fuel. The quality of fuel affects the white smoke produced in an engine. In general more volatile fuels give less smoke than heavier fuels of similar cetane number. High

cetane number and high volatility both improve the cold smoking performance of an engine. An overloading, also result in increase of black smoke. So it should be considered in designing.

4. Derating and Fumigatiton. At lower loads the air-fuel ratio obtained will be higher and hence the smoke developed will be less. However this means loss of output, fumigation consists of introducing a small amount of fuel into the intake manifold. This starts precombustion reactions before and during the compression stroke resulting in reduced chemical delay. Fumigation rate of about 11 to 15% gives best smoke improvement. However this improvement varies greatly with engine speed.

Q. 1.42. Draw a flow-chart showing different stages of engineering design. Explain why some stages are repeated several times.

Ans.
- Fig. 1.8. shows the flow-chart indicating different stages of engineering design.
- The ordered linearity of the vertical structure is a bit misleading and oversimplified. Each step in the process is in fact is *characterised by ambiguity.* At every step we have to make decisions that require more information than is available at that stage. Additional information is usually available only at much later stage and to reach that stage decisions have to be made now. *So some stages are repeated several times.*

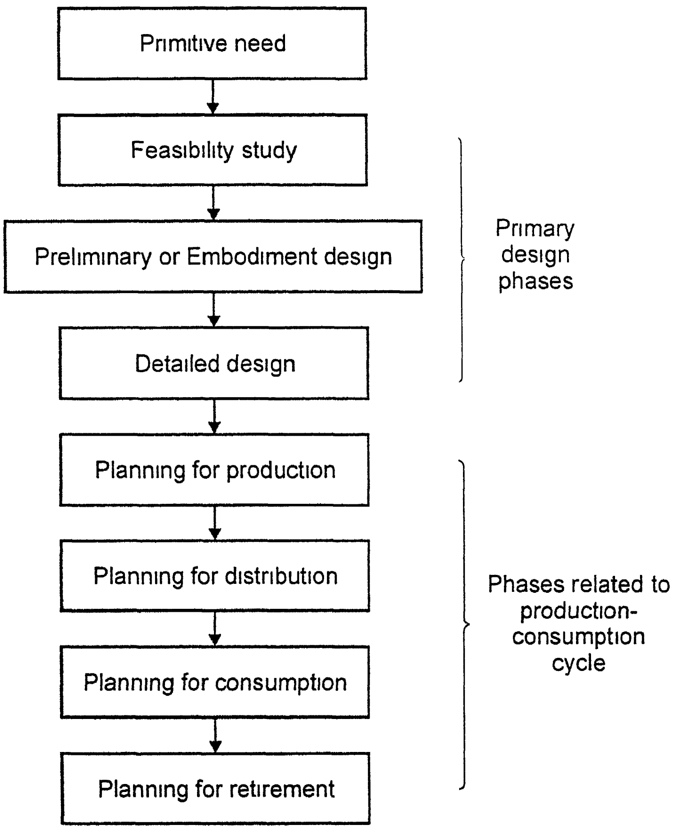


Fig. 1.8. Flow-chart showing different stages of engineering design.

Q. 1.43. What are the methods of mathematical optimisation?

Ans. For an optimal design, mathematical model of design is made.

Various mathematical models are based on mathematical programming techniques such as *linear and non-linear programming finite element techniques etc.*

— Simplex based models are well known; classical optimisation based on calculus are

used such as Kuhn-Tucker conditions, Lagrange multipliers, Gradient methods; Geometric programming techniques are used for achieving globally optimum designs.

— 'Fibonacci techniques' are employed for univariate search.

Q. 1.44. Why do design alternatives arise during the design process? Write briefly about any three design alternatives in use for : (*a*) Room heating and (*b*) Electric power cuts. Evaluate each of the alternatives in terms of cost, consumption and pollution.

Ans.
- During the design process the *design alternatives arise as a result of decisions made at design review stage.* The details of designs approved are changed several times as prototypes of each is developed and tested and evaluate. Here by evaluation we mean to determine the value, usefulness or strength of design with respect to a given objective. When any design developed does not fit into the objectives, alternative design issue arises.
- Design *alternatives* in use for (*a*) Room heating; (*b*) Electric power cuts are :

(*a*) Electric room heating :

(*i*) *Electric heater.* This is one of the common methods used in urban areas. Its cost *is less but electric consumption is more.*

(*ii*) *Electric converter.* Its cost is more than electric heater but consumption as compared to heater is *less and it heats evently.*

(*iii*) *Heating by solar energy.* Keeping in mind *pollution and running cost,* it is the *best.* But *initial cost is higher* than two alternatives.

(*b*) Electric power cuts :

(*i*) *Battery and inverter.* In this case, pollution is less but it supports less appliances. It works for a limited period of 2-3 hours.

(*ii*) *Electricity by biogas.* It produces no pollution but its initial cost is high for installing a biogas plant.

(*iii*) *Generator.* In generator we use kerosene and petrol as a fuel. The *capacity of the generator is best among the three but it creates noise and air pollution.* Costwise generator is cheaper because we have to use kerosene oil for running and petrol for starting the generator.

Q. 1.45. Engineering design starts with a need statement. Prepare brief need statements for the following:

(*i*) Washing machine.

(*ii*) Electric tube light.

(*iii*) Cellular phone.

Ans. Before we start working on any product developement, 'Need statement' is a must. The need for a particular product is identified through market survey and research Needs are collected and need statements are made from them. It may be understood that need statement does not directly state the detailed specifications of the product. To generate more design ideas and stimulate ideation process an indirect need statement is made.

(*i*) *Need statement* for **Washing machine :**

- The cost of the washing machine should be within the reach of common man and comparable to other alternatives.

- It should wash clothes nicely and fast.
- It should use less soap powder and water to wash clothes.
- Electricity consumption of the machine must be on lower side
- Size of the machine should be such as to fit in the bathroom or should occupy less space
- Life of the machine should be adequate.

(*ii*) *Need statement for* " **Electric tube light"** :

- The cost of the tube light should be within the reach of common man
- It should have quite an adequate life.
- It should glow nicely to illuminate the room or the place where it is to be fitted
- It should be easily available in the market.
- The defective piece if found should be replaced easily.
- It should occupy minimum space on the wall.
- Packing must be such that the product reaches safe to consumer's place

(*iii*) *Need statement for* **"Cellular phone":**

- Easy dialling and accessibility.
- Call diverting facility and SMS facility.
- Less weight of the instrument so as easy to carry
- Can store various numbers of mobiles and telephones.
- Monthly rental and call charges on the minimum side to match the competition
- Easy availability in the market.
- Compability with computer.

Q. 1.46. Explain briefly the following terms :

(*i*) **Layout design.**

(*ii*) **Stability.**

Ans. (*i*) **Layout design :**

- Layout design provides 'general arrangement' and 'form design (shapes and materials)'.
- It shows all drawings on spatial requirements and a rough analysis, so that designer can proceed to consider safety, ergonomics production, assembly, operation, maintenance and costs.

(*ii*) **Stability :**

- Stability refers to the basic stability of machine or its components and stable operation systems.
- Disturbance should be concentrated by stabilizing effects, that is by automatic return to the initial or normal position. For stability, designers must ensure neutral equilibrium since potentially unstable states do lead to a build-up of disturbances that might get out of control.

Q. 1.47. Explain the importance of 'aesthetic consideration' in design.

Ans. Aesthetic *is defined as being sensitive to art, showing good taste, being artistic and*

being concerned with appreciation of beauty. Aesthetic forms an *essential element of any engineering design.*

For designers, the concept of 'Aesthetic' includes the following :

(*i*) Function
(*ii*) Form
(*iii*) Unity (harmony)
(*iv*) Styling.

(*i*) ***Function.*** It underlines the form description of the actual operating function of the product. Function is not confined only to the mechanical operations of the product, but also to cost, enviroment use acceptance, maintenance and familiarity.

(*ii*) ***Form.*** It comprises of elements like line, porportion, colour and texture. The designers set a unique form by organising the above elements properly.

(*iii*) ***Unity.*** It signifies the harmonious combination of component of product. Unity in a product shows completeness in product.

(*iv*) ***Styling.*** It refers to decoration and ornamentation of product. Its scope is to attract maximum customers towards the product.

Q. 1.48. Compare the 'design synthesis' with 'design analysis'. Explain the basic procedure of 'design synthesis'.

Ans. Design synthesis :

- ***Synthesis*** *is putting together of parts or elements to produce new effects and* to demonstrate these *effects produced on overall order.* It involves search and discovery; and also composition and combination of individual findings or sub-solutions into an overall working system — that is association of components to form a whole.
- During the process of synthesis the information discovered during analysis of design is also processed. It is advisable to do synthesis on a global or system approach which means keeping in mind the general task for synthesis, while working on subtasks or individual steps (achieved at analysis).

Design analysis :

- **Design analysis** *is the resolution of anything complex into its elements and to do the study of these elements and of their interrelationships.* Analysis calls for *identification, definition, structuring, and arrangement.*
- In design analysis we try to *minimise errors* by formulating the problems and analysing them. It leads to separating essential from inessential and in case problems are complex, more transparent and subsidiary problems.
- Design analysis is also achieved by *structure analysis* and *weak line analysis.*
  — *"Weak line analysis"* is based on the fact that every system has *weakness* caused by ignorance, mistakes, ideas, external disturbance, physical limitations and manufacturing errors. During the development of system it is therfore important to analyse the design concept or design embodiment for the purposes of discovering possible weak line and prescribing the remedies.

Q. 1.49. Explain briefly the followings :

(*i*) Ergonomic design.

(*ii*) Visual aids for design presentations.

Ans. (*i*) Ergonomic design. An ergonomic design should consider the ergonomic aspects. It is a design which takes care of all the *factors which help the operator to work on machine and provide ease.*

Following factors help the operator of a machine :

- Sitting posture.
- Reduction in unnecessary fatigue.
- Working temperature (ambient).

(*ii*) **Visual aids for design presentations :**

- Visual aids are important in transmitting the massage in case of both effective or uneffective oral communications.
- Visual aid medium depends upon the size and importance to the audience.
- Visual aids are:
  — Limit slides.
  — Graphs.
  — Multimedia.

Q. 1.50. List the basic requirements for designing a complete machine element which a designer must consider.

Ans. The basic requirements for designing a complete machine element which a designer must considered are.

1 Strength	2. Rigidity
3 Reliability	4. Durability
5. Material	6 Cost
7 Efficiency	8. Appearance
9. Lubrication	10. Wear resistance
11. Standardisation	12 Sale
13. Operational safety	14. Ease of assembly and disassembly
15 Repair and maintenance	16. Servicing and control
17. Size and shape	18. Weight
19 Processibility	20. Simplicity.

Q. 1.51. State the factors which affect the design of a job.

Ans. The design of a job may be affected by the following *factors:*

1. Materials used.
2. Manufacturing processes.
3. Labour costs.
4. Financial problems.
5. Appearance of the job.
6. Modifications based upon practical experience.
7. Market conditions.

Q. 1.52. Explain briefly 'Design criteria'.

Ans. We can have *three design criteria* as given below

1. The part is made in large enough quantities, so that a moderate series of tests is feasible.
2. Failure of part would endanger human life, or part is made in extremely large quantities so that testing programme can be justified
3. The parts are made in such small quantities that testing is not justified at all

- A designer oftenly makes use of data available in data books Based on this data, the components are designed. Whenever exact analysis of stresses is not possible, high safety factor is adopted to take into account the uniform forces. *The purpose of all this design work is to prevent the failure of component while in service.*

Q. 1.53. What guidelines should be followed during designing a system?

Ans. While designing a system the following guidelines should be followed :

1 *Avoid orbitrary decisions.*

2 *Search for alternatives.*

3. Make use of solid models — solid models produced by computer graphics may provide faster paths to the goal with enhanced design results.

4. Increase the level of abstraction at which the problem is formulated.

5. Make tables of design functions and options and use them to develop competing design concepts.

6. In developing some design concept always pursue it to the limits, and then back off. The limits will be set by physical realisability or economic constraints.

7. *Aim for clarity of function.*

8. Exploit materials and manufacturing methods to the fullest.

9. *Develop a logical chain of reasoning for the design.*

Q. 1.54. What steps should be taken to enhance creative thinking as a design engineer?

Ans. The following *steps help to enhance creative thinking* as a design engineer:

1. Develope a creative attitude.
2. Unlock your imagination.
3. Be persistent.
4. Develope an open mind.
5. Suspend your judgement.
6. Set problem boundaries.

Q. 1.55. What do you understand by 'Generative process planning'? What are its advantages ?

Ans. Generative process planning *may be defined as a system that sythensizes process information in order to create process plan for a new component automatically.*

Process plans are created from information available in a manufacturing database, with little or no human intervention. Upon receiving the design model, the system can generate the required operations sequence for the component. Knowledge of manufacture is encoded into efficient software.

The generative method of process planning essentially consists of the following four *steps*·

1. Describe a part in detail.
2. Describe a catalogue of process available to produce parts.
3. Describe the machine tools that can perform these processes.
4. Create the software to inspect the part, process and available machinery to determine whether all three are compatible.

Advantages :

(*i*) New components can be planned as easily as existing components.

(*ii*) It can generate consistent process plans rapidly.

(*iii*) It can potentially be interfaced with an automated manufacturing facility, to provide detailed and up-to-date control information.

HIGHLIGHTS

1. *Design* is a creative activity — it is the creative part of engineering
2. Product design and process design pertain to design for production.
3. Some important aspects of design are.
   (*i*) Need analysis. (*ii*) Feasibility study
   (*iii*) Preliminiary design (*iv*) Detailed design.
4. A *model* is a representation of a system in a convenient fashion so that conjectures made about the preformance of the system can be readily tested
5. Various types of models are: *Ionic models, Analogic models, and Symbolic models.*
6. Design may be classified as follows:
   (*i*) Elemental design (*ii*) System design
   (*iii*) Rational design (*iv*) Optimum design
   (*v*) Empirical design (*vi*) Industrial design
   (*vii*) Computer design.
7. The process planning begins where the product design ends.
8. *Generative process planning* may be defined as a system that synthesizes the process information in order to create a process plan for a new component automatically.
9. *Ideation* means the process of generation of ideas.
10. *Need analysis* is the process of transforming need statements into statements of goals.

OBJECTIVE TYPE QUESTIONS

Fill in the blanks or Say 'Yes' or 'No' :

1. Design is a .... process.
2. .... implies newness, but it is often concerned with the improvement of old products as it is with the creation of new ones.
3. The design ability requires both science and art.
4. The feasibility of a design must be checked at various stages.
5. The objective of .... design is to select the best solution from the possible alternatives.

6 The need analysis concludes with a specification which provides the starting point for the feasibility study.
7. A .... is representation of a system in a convenient fashion so that conjectures made about the performance of the system can be readily tested.
8. Scientific methods used by engineers involve the representation of the laboratory known as ....
9. .... models represent things as they appear and so sketches and drawings of all types fall under this category.
10. .... models represent scientific features of the design by using an analogy.
11. .... models describe some aspects of product by using words, numbers or mathematical symbols.
12. A symboilic model is important because it leads to quantitative results.
13. . ... planning is the sub-system responsible for the conservation of design data to work instruction
14. ... . is an intermediate stage between designing the product and manufacturing.
15. The process planning begins where the........... design ends.
16. .... planning may be defined as a system that synthesizes process information in order to create a process plan for a new component automatically.
17 .... is defined as the branch of science which is concerned with the generation of ideas, their collection, analysis and presentation.
18 .... means the process of generation of ideas.
19. Need is the starting point in design.
20 .... is the process of transforming need statements into statements of goals.

ANSWERS

1. creative	2. Creativeness	3. Yes
4. Yes	5. preliminary	6 Yes
7 model	8. modelling	9. Ionic
10. Analogic	11. Symbolic	12. Yes
13. Process	14. Process planning	15. product
16. Generative process	17. Ideonomics	18. Ideation
19. Yes	20. Need analysis.	

THEORETICAL QUESTIONS

1. Define the term 'Design'?
2. What is engineering design? Explain?
3. Explain briefly 'design for production'?
4. What is the difference between product design and process design?
5. What are the characteristics of a good designer?
6. List the main road blocks to the creative approach in designing?

7 Explain briefly the following aspects of design :
   (*i*) Need analysis
   (*ii*) Feasibility study.
   (*iii*) Preliminary design.
   (*iv*) Detailed design.
8. Explain briefly the concept of model and modelling?
9 How are models classified?
10 Explain briefly the following models:
   (*i*) Ionic models.
   (*ii*) Analogic models
   (*iii*) Symbolic models.
11. Give the classification of designs?
12 Write down the logic procedure of design.
13. Explain very briefly the following types of design :
   (*i*) Elemental design.
   (*ii*) System design.
   (*iii*) Rational design
   (*iv*) Optimum design.
   (*v*) Empirical design.
   (*vi*) Industrial design.
14. What is process planning? Explain.
15. What information is required to do process planning?
16. List the steps involved in process planning.
17 Explain breifly the following types of process planning .
   (*i*) Manual process planning.
   (*ii*) Automated process planning.
   (*iii*) Generative process planning.
18. What are the advantages of computer-aid process planning?
19 Define the term 'Ideonomics'?
20 What do you understand by the term 'Ideation'?
21 List the elements which are involved in the process of ideonomics?
22 Explain briefly the followings:
   (*i*) Developed ideas
   (*ii*) Adaptive ideas
   (*iii*) New ideas
23. Explain briefly the following methods of accumulating ideas:
   (*i*) Idividual approach.
   (*ii*) Team approach.
   (*iii*) Research method
   (*iv*) Survey method

24. What is need? explain.
25. What are the types of need?
26. What is 'statement of need' ?
27. Which points should be considerd for identification of a problem?
28. What are the main objectives of the methodology of 'Identifying customer needs'?
29. What is need analysis? Explain.
30. What are the requirements of need analysis?
31. List the points which should be considered while analysing a need.

❑❑

2

Product Design–Development

2.1 Product design, 2.2 Effect of product design on the production cost, 2.3. Requirements of a good product design, 2.4 Factors affecting product design, 2.5. Factors to be considered during product design, 2.6 Product development, 2.7. Product development process, 2.8 Specification – Definition – points to be considered while preparing the product specification – deficiencies of any specification – technical specification – standard specification – product design specification, 2.9. Standard of performance, 2.10 Environmental factors affecting design of production system ***Question with Answers*** *— Highlights–Objective Type Questions–Theoretical Questions*

2.1. PRODUCT DESIGN

• **Product design** *is considered with design of some appliances, systems components, and other similar unit-type items, for which there appears to be market* Such a product may be a lawn sprinkler, a toy, a food grinder, an electric clock, a valve, an electrical component, and other item that can be readily marketed as a commercial unit. Such products are *designed to perform a specific function and to satisfy a particular need*

"*Total product design*" includes *not only the design of an item, but the testing, manufacture, and distribution of the product as well.*

Design does not end with the solution of the problem through creative thinking. The *design phase of a product to be sold in the market ends only when the item has received wide acceptance by the public.*

- The design problems may be classified as being either a *system design* or a *product design*, even though it may be quite difficult in many instances to recognize a problem as belonging entirely to one classification or the other.

A **system design** *problem involves the interaction of numerous components that together form an operating unit.*

The creative individual, after initially recognizing a need or desire for a new product, enters the next step in the design procedure—*research and exploration phase* During this phase, the possible ways and *feasibility of fulfilling the need are investigated.*

- *The ultimate success of a design is judged on the basis of its acceptability in the market place and how well it satisfies the needs of a particular culture.*

2.2. EFFECT OF PRODUCT DESIGN ON THE PRODUCT COST

The cost of the product is decidedly influenced by the product design. A complicated product design will associate high cost and vice versa.

Following are the *components of the product cost*:

1 Direct material cost
2. Direct labour cost.
3. Direct expenses.
4 Indirect expenses.

— *The product cost can be reduced if better mutual understanding exists between the design department and the manufacturing division* If they mutually decide to make use of the existing equipment with a little additional tooling etc., it may be possible to reduce cost of the product.

— Product may be *redesigned to lower the product cost* in order to compete in the market. Product cost can be reduced by applying the concept of 'Value analysis'. The product cost can also be reduced if the following aspects at the design stage are considered:

(*i*) A product should be designed with minimum of material to reduce both machining costs and original material costs.

(*ii*) A product should be designed of a material which in cheaper, correct and easily workable and machinable etc.

(*iii*) A product should be designed with parts as fewer as possible. Lesser the number of components, lesser is the product cost.

(*iv*) A product should be designed out of as many standard parts as possible, in order to cut down the product cost.

(*v*) Too high a surface finish, simply to add to sale appeal will entail high production cost.

(*vi*) To reduce the product cost, some component parts of the product which cannot be economically and easily manufactured in the concern itself, should be purchased from outside suppliers.

(*vii*) The design of the product should be simple so that the product can be manufactured without much consideration.

2.3. REQUIREMENTS OF A GOOD PRODUCT DESIGN

The requirements of good product design are :

1. Customer satisfaction
2. An adequate profit.

1. Customer satisfaction. In order to achieve satisfaction of customer, the product should have the following *characteristics* :

(*i*) To function correctly.

(*ii*) To possess desired degree of accuracy.

(*iii*) To process required standard of reliability.

(*iv*) To operate easily and smoothly.

(*v*) To be sufficiently rugged to withstand all but exceptionally rough handling

(*vi*) To be of reasonable price to compete with other products in the consumer market

2. An adequate profit. In order to make an adequate profit the points need be considered are ·

- Manufacturing process should be decided on the basis of the product quantity to be manufactured. Small parts on mass scale may be produced by 'Die casting' rather than the sand casting.
- The use of standard component parts wherever possible can lead to great saving
- A well designed product should consist of minimum number of parts
- Good design will call for minimum number of operations.
- Good product design should not extend through–put time
- A well designed product should be easy to pack and distribute

2.4. FACTORS AFFECTING PRODUCT DESIGN

The following *factors affect product design.*

1 Technical factors.
2. Industrial design factors
3 Designing for production—Economic factors.

1. Technical factors:

(*i*) *Operating conditions:*
— Conditions of noise, vibration and heat, etc.
— The type of workers.

(*ii*) *Performance.*
— Type of materials used.
— Speed, feed, etc.
— Length of time
— Accuracy.

(*iii*) *Maintenance:*
— How often maintenance and repair will be required?
— Whether planned or breakdown (maintenance) policy will be adopted?

(*iv*) *Company experience:*
— Has the product been designed by the company before?
— Has the company experience or expertise to design the product?

2. Industrial design factors:

(*i*) *Function*
— Will the product function at minimum cost?

(*ii*) *Appearance·*
— Does the product has a pleasing appearance?
— Does it create Esteem value?

(*iii*) *Ergonomics:*
— Does the use of product cause excessive fatigue?
— Does the product fulfill the principles of "Fitting the job to the workers"?
— Is the product suitable for human use?

3. Designing for production—Economic factors:

(*i*) *Materials*:

— Is the minimum amount of material being used in making each component part?

— Is the cheapest material, consistent with technical design requirements, being used?

— Is the waste during production being minimized?

(*ii*) *Methods*:

— Can the product be manufactured with the available (direct and indirect) labour?

— For production quantity required, can the most productive equipment be employed?

— Does the product design make use of factory layout?

— Does the product design allow the maximum possible tolerance?

— Does the product design permit the use of exciting or otherwise simple economical tooling?

— Overheads involved

(*iii*) *Standards.*

— Is design simple?

— Does the design make use of standard parts?

— Does the design keep types and varieties of parts to a minimum?

(*iv*) *Finish.*

— Is the right finish (including painting, polishing, electroplating, etc.) being used consistent with cost, endurance and appearance requirements?

2.5. FACTORS TO BE CONSIDERED DURING PRODUCT DESIGN

During product design, the following *factors* should be considered:

1. Product variety verses standardisation.
2. Modularisation
3. Design simplification.

1. Product variety verses standardisation. The design of a product (or a service) can be affected by two distinctly different priorities: *The higher the standardisation, the greater will be the ease in producing the product.* On the other hand, the *customers have different needs and by adding variety, one can satisfy more customers.*

Standardisation *attempts reduction in variety and better use of productive facilities, thereby achieving lower unit costs* The standardisation entails the following *advantages*

(*i*) It simplifies operational procedures and thus reduces the need for many controls

(*ii*) The organisation can buy raw materials and components in bulk and thus get quantity discounts.

(*iii*) It enables steady flow of materials through work centres and thus reduces the number of production set-ups related to change in flow

(*iv*) It reduces the total inventory of raw materials, work-in-process and finished goods

(*v*) Since the effective volumes become larger as the variety is reduced, high-volume production methods become viable thus giving economics of scale in production itself.

- *"Standardisation"* may be a very good approach to product design as long as cost is the primary basis of competition *Otherwise, one can design a product to suit the diverse needs and taste of the customer. By adding "variety", an organisation attempts to satisfy the varied needs and taste of its customers and competes on non-price considerations as well.*

2. Modularisation. *"Modularisation" is a technique employed to obtain variety or perceived variety and yet hold down cost* A product is designed using modules or sub-assemblies that are interchangeable and each different combination of modules give a new variety of the product

3. Design simplification. The main purpose of the design simplification is to simplify the design so that the product or its parts become simpler to produce. It gives payoffs in terms of lower production costs and in some cases by lower costs as well

The following key elements should be considered in product design

(*i*) Function	(*ii*) Cost	More important
(*iii*) Quality	(*iv*) Reliability	
(*v*) Appearance	(*vi*) Environmental impact	Less important
(*vii*) Product safety	(*viii*) Productivity	
(*ix*) Maintainability	(*x*) Timing	
(*xi*) Accessibility		

2.6. PRODUCT DEVELOPMENT

A **product** is *something sold by the enterprise to its customers and* **product development** *is the set of activities beginning with the perception of a market opportunity and entry in the production, sale and delivery of a product*

Characteristics of successful product development. The primary objective for product development in a manufacturing enterprise results in the products that can be produced and sold profitably. Following are the *specific dimensions* which relate to profit by product development

(*i*) Product quality.
(*ii*) Product cost
(*iii*) Development time.
(*iv*) Development cost
(*v*) Development capability

Functions central to a product development project. The following functions are central to a product development project.

1 Marketing.
2 Design.
3 Manufacturing

1. Marketing:

- This function mediates the interactions between the firm and its customers

- Marketing often facilitates the identification of product opportunities.

2. Design. The design function leads the definition of the physical form of the product to best meet the customer need. In this context the design function includes engineering design (mechanical, ergonomics, user interfaces).

3. Manufacturing:

- This function is primarily responsible for designing and operating the production system in order to produce the product
- When broadly defined, this function also includes purchasing, distribution and installation.

2.7. PRODUCT DEVELOPMENT PROCESS

A **product development process** *is the sequence of steps or activities that an enterprise employs to conceive, design and commercialize a product.*

Following are the *reasons* for which a well defined development process is required / needed:

(*i*) Quality assurance.
(*ii*) Co-ordination
(*iii*) Planning.
(*iv*) Management.
(*v*) Improvement.

Phases of generic product development process. The following are the *six phases* of a generic product development process.

1 Planning.
2 Concept development
3 Planning and product arch.
4. Detail design.
5 Testing and refinement.
6. Production and manufacturing

2.8. SPECIFICATION

2.8.1. Definition

Specification *is defined as detailed description of the required characteristics of a device, equipment, system or process.*

A specification is intended to be a statement of a standard of quality. The ideal specification would uniquely define the performance criteria, the qualities and characteristics of components and materials necessary to serve efficiently for a given application, how the specified parameters of performance will be tested, and penalties for falling short for requirements etc.

Effectiveness of specification lies in how clearly and unambiguously it is written and how enforceable the provisions are.

- *'Specification' is an acceptable outcome for designing, that has yet to be done.*

2.8.2. Points to be Considered while preparing the Product Specification

While preparing the production specification the following points should be considered

1 To use simple English (avoid ambiguous phrases)
2 To ascertain that the given specification is complete and concise
3. To ensure accuracy of specification.
4. To provide flexibility for incorporating improvements at later stage
5 To ascertain that the specification is reasonable to assigned tolerances

- Specifications may also include the following.
  — Objective
  — Operation
  — Operation constraints
  — Limitations during erection
  — Manufacturing constraints
  — Environment
  — Functional requirement etc.

2.8.3. Deficiencies of any Specification

The deficiencies of any specification can be.

(*i*) Specification may be based on inadequate or improper criteria with respect to type of service required;

(*ii*) It may be so loose as to admit product components/material of inferior quality than that intended for the application,

(*iii*) It may be overly restrictive and thus exclude an equally or more efficient component;

(*iv*) It may make no provision or inadequate provision, for proper enforcement.

- Practically, specification should not be drawn for ideal conditions, but for a state that is possible to obtain at reasonable cost under existing conditions of design and manufacture.

2.8.4. Technical Specification

A technical specification defines needs (requirements) for others to meet. Specifications may be required to define a *material,* or a *process,* or a *product.*

(*i*) ***Material specification.*** A material specification must include the following

- *Identification*—provide a generic, or family—tree type of identification of the basic material
- *Key properties*—chemical and/or physical properties in tabular or graphical form
- *Acceptance criteria*
- Packaging
- Marking.

(*ii*) ***Process specification.*** It defines those parameters which must be controlled to obtain a desired outcome. It generally contains the following:

- *Identification*—Provide a short name, which is descriptive

- *Scope and purpose*— To describe what process covers, how it is to be used and what to expect.
- *Application materials.*
- Required results
- Process limits
- Precautions/warnings

(*iii*) ***Product specification :***

- It defines the functional requirement that components/system must meet
- It provides some flexibility to the supplier in meeting the requirements.

2.8.5. Standard Specifications

- A standard specification provides *standard definitions and methods of testing*
- These usually represent the *combined knowledge* of the producer and consumer and thus reduce the possibility of misunderstanding to a minimum.
- These tend to result in a *more uniform product* and *reduce* the member of required varieties of stocks, lower the attended waste and thus lower the cost.

2.8.6. Product Design Specification

The **product design specification** (**PDS**) *is the basic reference source of the design activity* However, *it must be dynamic document that evolves and changes with the progress of the design* Its development starts with the market research, followed by patenting searching and a thorough examination of the technical literature.

The following elements go into product design specification:

1. Performance	2 Environment
3 Service life	4. Maintenance and logistics
5. Target product cost	6. Competition
7. Shipping	8 Packing
9. Quality	10. Manufacturing facility
11. Size	12. Weight
13. Aesthetics	14. Materials
15. Product life span	16. Standards and specifications
17. Ergonomics	18. Customer
19. Quality and reliability	20. Shell in storage
21. In-house processes	22. Design schedule
23 Testing and inspection	24 Safety
25. Company constraints	26. Market constraints
27. Patents	28. Social and political factors.

2.9. STANDARD OF PERFORMANCE

- **Standards of performance** *are a set of broad requirements that cover a wide field which may include reliability level, safety, convenience in use, adaptability under*

various conditions, ease of maintenance and cost. Each of these must be considered and due attention paid while designing At the need analysis stage one must list the relative performance parameters and also, decide the minimum acceptable performance on each of these parameters. This only settles the minimum which must be met Competing designs are judged depending on how much they better these minimums

- A large complex system functions in a highly integrated and independent manner. It is essential that such systems are designed to achieve an overall performance, reliability, schedule, cost. maintainability, power consumption, weight and life expectancy. It is important to understand how the performance of a system can be determined System behaviour can be studied as a function of various parameters *Complex systems* can be characterised by large number of inputs, outputs and functions to be performed *The performance of these systems can only be determined by statistical techniques and the performance index will involve some probability distribution*
- In large complex systems, there can be *many sources of errors* caused by dynamic lags, disturbances, manufacturing tolerances, aging, variations due to environmental changes, etc Each has effect on the overall performance of the system It is thus essential that we should be able to study the effect of each on system performance, and depending on desired performance, the range of variation of error of each type can be estimated. Thus selection of components and equipments with finite tolerances should be specified depending on overall performance desired and practical considerations like development costs etc.
- *The standards of performance* may be arrived at *by careful considerations of the possible adverse conditions under which the product may be used and manner in which it is used An appraisal and a thorough analysis of the existing products, critical analysis if any, also helps in establishing the performance standards*

2.10. ENVIRONMENTAL FACTORS AFFECTING THE DESIGN OF PRODUCTION SYSTEM

Every design problem has some environmental factors, that may adversely affect the performance The designer should identify these factors as well as the range to which the design will be subject to.

The *environmental factors that need be considered are:*

1. Ambient temperature.
2. Ambient pressure.
3. Ambient humidity.
4. Indoor/Outdoor location.
5. Seismic factors.
6. Vibration.

QUESTIONS WITH ANSWERS

Q. 2.1. Discuss the interrelationship between design, materials and manufacturing to produce a product. Choose a suitable example to explain the interrelationship.

Ans. *An intimate relation exists between design, material and production process.*

In conceptual phase, in physical realizability we start with a certain material after verifying its suitable processing characteristics. Once the design is ready, the stress analyse is made to check whether the given material is strong enough or not

- For example, quoting Gupta and Murthy, 'Engineering design method' they state 'An aircraft wing is designed to withstand the wind load. After it size is fixed up, the dead load due to its weight is taken into account and redesign is done'. The producibility requirements are also verified whether the aerofoil section can be made of CAM (Computer Aided Manufacturing) system.

Q. 2.2. Material selection is the problem solving process like any other aspects of the engineering design. Describe the steps usually considered in the process of material selection.

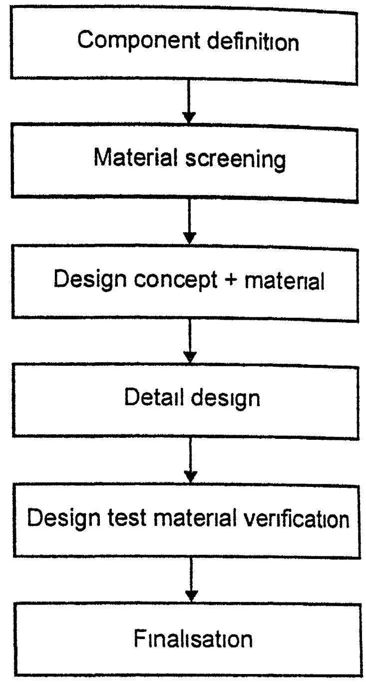


Fig. 2.1. Material selection process.

Ans. Material selection is a process which proceeds during design process as shown in Fig. 2.1. It will be seen that in each of these design phases, *material plays a vital role as much as the design process.* The materials vary in quality and in price. A good designer will select the least expensive material. The expected life of the part or a machine is also taken into consideration. The longest is the life desired, the best should be the grade of material used.

The selection of the design also depends upon the quality of the required part or machine to be used for manufacturing. The same is in case the process of manufacturing is to be selected according to the requirements of the material selected and design accepted for the manufacture

The manufacturing process is selected according to the local environment and desired quality of part or machine to be manufactured.

Q. 2.3. For a particular product a large number of feasible alternative designs are available. Discuss the theory of critical decision making for selecting the best.

Ans. Fig. 2.2. Illustrates the decision making process.

Out of various alternatives available with the designer, he arrives at an expected consequence or decision *after going through both desirable or undesirable aspects of alternatives in the depth, keeping in view above two mentioned and other required aspects, as it is most important*

stage After making decision the design will go to production unit. Hence, we can say that the decision criterion is the course of action which leads to final desired result.

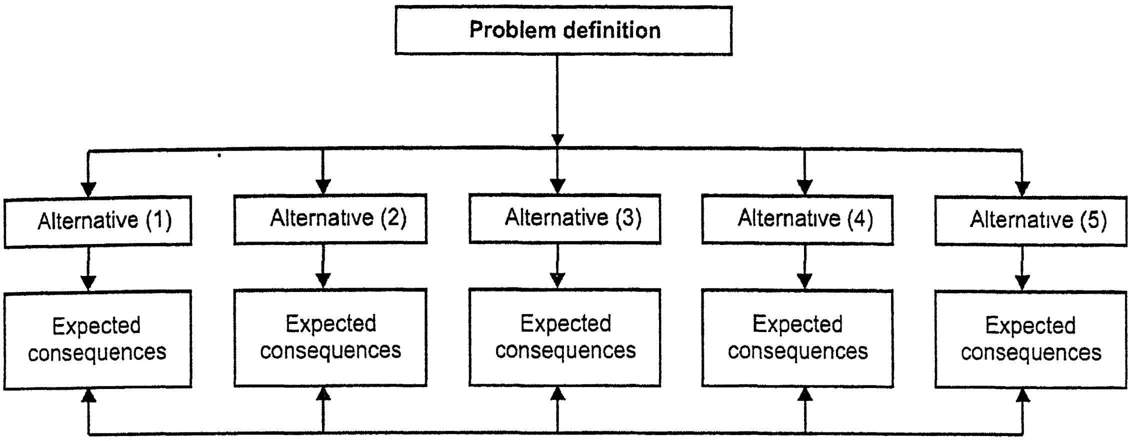


Fig. 2.2. Decision making process.

Q. 2.4. Write down 'Five phases' which are considered in 'value analysis'.

Ans. *Five phases of value analysis are:*

1. Information gathering after project selection.
2 Brainstorming for idea generation.
3. Analysis
4. Evaluation
5. Implementation.

Q. 2.5. Name the characteristics which make the product development challenging.

Ans. The characteristics which make product design a challenging task in today world are:

1. Trade offs
2. Demands from the users of products at affordable costs with high quality performance and appearance.
3. Short time available for design, development and testing of product.
4. Increase in number of competitors locally, internationally both, who can supply a product of equivalent value.
5. Fast changing attitudes of customers towards products with fast advancement of technology.

Q. 2.6. Explain how the 'Product Design' and 'Product manufacturing' take care of the environment protection.

Ans. 'Product Design' and 'Product Manufacturing' take care of environmental protection by *adopting suitable measures.*

Example. During 'Activity Analysis' step of design, which is an Input-Output analysis, the designer estimates the desirable and undesirable inputs and outputs from the design. Any undesirable output such as noise, vibration, poisonous emissions, glare etc. are estimated at the design stage itself. Production people also participate in the production design stage to support

factors which do not create environmental pollution. *Foundaries are now-a-days being replaced by fabrication plants to minimise pollution*

Q. 2.7. For designing a product, explain how analysis of need is reflected in the specifications.

Ans. The sole objective of the manufacturer is *"Customer satisfaction* The product has to meet certain expectations related to quality and performance or functional requirement, attribute for which any desired dimension or property has been laid down. *Degree of permissible variation from the desired parameter is called* ***tolerance.***

For manufactured products the general characteristics perceived by the consumer must be translated into engineering specifications for every part or subassembly so that there will be no ambiguity about their processing at specific workstations Product specifications may be very precise, like the engineering blue prints for a machine part or formula for producing a petroleum product by an oil refinery Thus, the specification for a shaft be 30 mm ± 0 001 mm.

— However, specifications can be more general, as in the case of potteries of decorative type for tourist attraction, recipes for restaurants and so on.

— Specifications for service function tend to be less precise as for example, waiting time in queue in a bank etc due to strong dependences on factors

- A good *example of developing specifications* has been given by Gupta and Murthy in their book 'An Introduction to Design Method'. In the blackboard example cited by them it has been pointed out how the height for a blackboard for a classroom writing purposes can be derived from a knowledge of comfortable low reach of a tall professor and a comfortable highest reach of short professor The width of the blackboard can of course be derived from width of classroom or lecture hall

The above example shows how analysis of need and specification of product are interrelated.

Q. 2.8. What are methods of evaluating feasible alternative product designs?

Ans. After having selected various alternatives for solution of a design in *feasibility phase* designer faces the task of taking a decision for suitable feasible alternatives. The designer has to make assessment of the available solution in stages and then the promising ones should be examined in detail.

Technical feasibility *is the most vital aspect which comprises reliability, safety, ergonomic manufacturing process and maintainability of the product.* Other aspects are *cost* and *long term future of the product.* After examining all the factors the designer can eliminate a few solutions and remaining alternatives are examined intensely. The evaluation thus starts at a superficial level and more and more detailed study is conducted. With the increase of elimination process with each round of technical assessment the designer should make the *economic assessment which helps for final decision making.*

The final decision making is *of great importance since the design* selected will go for manufacturing and therefore following important techniques are also employed for making final decision:

(*i*) Operation research. (*ii*) Mathematical analysis.

(*iii*) Models. (*iv*) Computer simulation.

Q. 2.9. Describe various human factors that need to be considered in engineering design of products.

Ans.
- *Human factors engineering is recognized as a specialised discipline.* We have often experienced that human error is chiefly responsible to a large number of equipment failures. Hence it becomes most essential to pay greater attention to human reliability during the design, manufacturing and operation phases of engineering systems.
- *A system always revolves around humans.* The overall reliability of all engineering systems is function of human reliability. If we observe the human factor principles during system design, it will immensely improve the reliability of human aspect Another way of increasing human reliability is by careful selection and imparting training to concerned personnel.
- The human factors which enter design consideration are:
  (*i*) Anatomy.
  (*ii*) Physiology
  (*iii*) Psychology

These factors clearly show that personnel involved should have good anatomic structure, there physiological health should be sound and psychology while working at work place should be positive and work oriented Due to slackness of any of these factors the work in factory or in designing process will either fail or become non-competitive.

Q. 2.10. What factors affect the quality of the product? Explain briefly.

Ans. The following nine M's directly affect the quality of products and services and so these should be identified and dealt with appropriately to obtain good results:

1. Money.
2. Material.
3. Manpower.
4. Market for products, services.
5. Motivation of employees.
6. Modern information approaches.
7. Management.
8. Machines used.
9. Mounting product needs.

Q. 2.11. While designer makes 'choices of resources' he should also consider 'customer's interest' and 'manufacturer's considerations'. Discuss the statement in detail.

Ans. In the *'past'* designer used to carry out the design and left it for the production people to sort out the problems of production. The *'modern approach'* of *simultaneous engineering is a team approach in which a team comprising of marketing personnel, designer, production people, quality people and vendors representative faculty arrive at an acceptable design solution.*

Q. 2.12. Discuss the features of planned obsolescence in products, which are being designed at present.

Ans. New technologies, in modern times, are developing at a very fast pace. Designers intentionally design product for a limited life, keeping in mind the likelihood of invasion by new

technology as well as change in the taste of customers with the passage of time While in the past automobiles were designed for a life of at least 15 years, the present trend is to design them for a useful life of 5 to 6 years. Due to the strategy of planned obsolescence, the materials recommended by the designers are:

- *Use thinner gauge sheet steel, replacement of metals with plastics as well as use and throw strategy at the component level.*

Q. 2.13. List the characteristics which should be considered in the design of the parts.

Ans. Following are the *important characteristics* which deserve attention in the design of parts :

1. Ductility or the amount of deformation before failure.
2. Wear and tear, friction characteristics.
3. Resistance to corrosion under operating conditions.
4. Impact strength and fatigue failure.
5. Heat conducting properties
6. Electrical insulating properties.
7. Tensile, compressive, shear, bending and endurance strength of the material.
8. Possibility of obtaining improved properties by heat treatment.
9. Strength and creep at elevated temperatures.
10. Stiffness or resistance to deformation under load.
11. Weight of finished part

Q. 2.14. What are the challenges of product development ?

Ans. It is hard to develop great products. Only few companies are highly successful more than half the time. The odds present a significant challenge for a product development team. These challenges are listed below :

1. Trade offs
2. Dynamics
3. Details
4. Time pressure
5. Economics
6. Creations
7. Satisfaction of societal and individual needs
8. Team diversity
9. Team spirit.

Q. 2.15. Explain briefly 'Concept development—The front-end process'.

Ans. The concept development phase requires more coordination among the functions than any other. The front-end process generally contains the following *distinct activities:*

1. Identifying customers need.
2. Establishing target specification.
3. Analysis of competitive products.
4. Concept generation.
5. Concept selection.
6. Concept testing.
7. Setting final specifications
8. Project planning.

9. Economic analysis.
10 Modelling and prototyping.

Q. 2.16. Explain briefly 'The customer need activity in relation to other concept development activities'.

Ans. The process of identifying customer needs is an integral part of the larger product development process and is closely related to :

— Concept generation;
— Concept selection;
— Establishing product specifications.

Figure 2.3. shows the customer need activities in relation to other front end product development activities, which collectively can be thought of as the concept development phase.

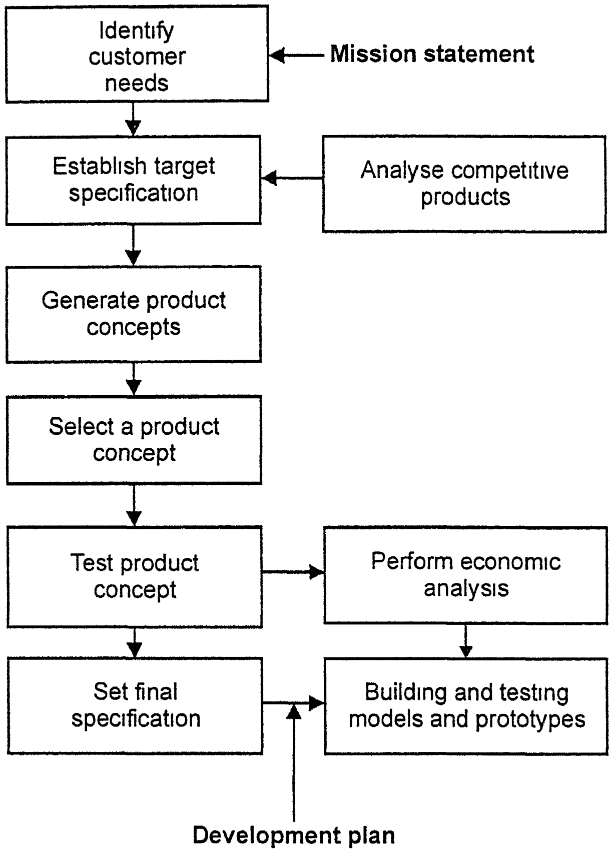


Fig. 2.3. The customer need activity in relation to other concept development activities.

- The concept development phase implies a *distinction between customer needs and product specifications.* Customer needs are largely independent of any particular product that we might develop, they are not specific to the concept that we eventually choose to pursue. A team should be able to identify customer needs without knowing of or how it will eventually address those needs. On the other hand *specifications do*

not depend on the concept we select. The specifications for the product we finally choose to develop will depend on what is technically and economically feasible and on what our competitors offer in the market place as well as on customer needs.

- The methodology to identify the customer needs involves the following *five steps:*
  (*i*) To collect raw data from customers.
  (*ii*) To interpret raw data in terms of customer needs.
  (*iii*) To organise the needs into hierarchy of primary, secondary and tertiary needs (if required).
  (*iv*) To establish relative importance of needs.
  (*v*) To reflect and review the results and process.

Q. 2.17. What is product planning process? Explain.

Ans. The product plan identifies the portfolios of the products, which are to be developed by the organisation and it also identifies the timing of their introduction to the market. The planning process considers the opportunities available from various sources for development of product and suggestions from marketing, research, customers, benchmaking of competitors, current project development team. From these opportunities portfolio of project is chosen and timing of projects is set and required resources are allocated.

Product planning consists of the following *five steps:*

1. Identify opportunities.
2. Evaluation and prioritization of projects.
3. Allocation of resources and timing for plan.
4. Completion of pre-project planning.
5. Reflection on the results of process.

- *Mission statement* is a document which summarises the directions to be followed by the product development team It may include some or all of the following information:
  — One sentenced description of the product
  — Key business goals.
  — Target markets.
  — Assumption and constraints of all the people affected.

Q. 2.18. Discuss the relationships of 'Functional design' and 'Production design' in determining a product design that meets functional requirements, cost considerations and limitations of available process.

Ans. Product design *depends upon 'Functional design' and 'Production design'*. In addition a good product design should also be cost effective. That is, it should be economically worthwhile and the user should be willing to pay more than its cost of production.

— *All design activity starts with market research which establishes the need for the product.* Market research also throws light on what function the product is supposed to perform to fulfil the customer needs.

— ***Functional analysis*** helps in development for conceptual design in the "development phase". After the "development phase", the detailed design is made in which

'Engineering drawings' are prepared for the parts, subassembly and assembly showing tolerances, clearances, and material used.

— ***Production design.*** Product development and design should consider whether a design has a good compatibility with material and production process for making a producible design. A typical *example* is that of a pulley in which curved arms are provided so that during production there are no casting problems and high tensile stresses being set up in arms during casting solidification are prevented Therefore, it is always suggested to take care of production process (involved in manufacturing the required product) in designing the product.

Q. 2.19. Explain briefly the following:

(*i*) Developing modular products and size ranges.

(*ii*) Visual aids for design presentations.

Ans. (*i*) **Developing modular products and size ranges :**

- Developing *modular products and prototypes* are required by design team to know about both analytical and physical approximation of the product. Armed with these, team can predict whether or not particular set of specifications (such as ideal target values) is technically feasible by exploring different combinations of design variables.
- *Size ranges* provide a rationalisation of design and production procedure. By size range we refer to technical facts (machines, assemblies or components) for wide sphere of applications Size ranges also help design team to develop modular products.

(*ii*) **Visual aids for design presentations:**

- Visual aids are important in transmitting the message in case of both effective or uneffective oral communications
- Visual aid medium depends upon the size and importance to the audience.
- Visual aids are:
  — Limit slides;
  — Graphs,
  — Multimedia

Q. 2.20. What types of information are required to give any specification?

Ans. The following two type of information are required in giving any specification:

1 Quantified characteristic

2 Unquantified characteristic.

1. Quantified characteristic. This type of characteristic includes the *physical characteristics* such as:

— Load on structure;

— Output power;

— Ambient pressure and temperature variation;

— Frequency of use,

— Expected life;

— Reliability etc

2. Unquantified characteristic. This characteristic includes:

— Appearance;

— Safety standards;

— Service requirements etc.

Q. 2.21. Enumerate and explain variety of needs which can generate ideas for the development of new product.

Ans. Some of the needs which give rise to variety of ideas could be *classified* as follows:

1. Primary needs :

Example. Functional needs and safety needs.

2. Secondary needs :

Example. Cost consideration etc.

3. Tertiary needs :

Example. Aesthetics etc.

The classification depends on the *"product type"*, *e.g.,* for *ornaments,* aesthetics form *primary need* while for *machine* tools aesthetics form *tertiary need.*

Q. 2.22. Design specifications of a product are drawn up at the starting point of design process, Why? What aspects or factors should be taken into account in design specifications? Explain briefly with suitable examples.

Ans. After the designer and sponsor have agreed on the 'Preliminary need statement', that is, they have settled on the essential nature of the problem, *the next step is to analyse that need to obtain complete definition of it.* There are usually two aspects in obtaining this definition, namely :

(*i*) The specifications;

(*ii*) Performance parameters or standards of performance.

"Specification", roughly speaking, refer to the normal functional requirements of a design which every design concept must meet and *"Standards of performance"* refer to those standards against which the competing design can be judged.

Examples :

- The requirement that a **bicycle** must be able to carry a man weighing 90 kg and, in addition, a luggage weighing 40 kg would be a *"specification"*, and the requirement that it should be durable would be a *"standard of performance"*. What the dividing line between the two types of requirements should be is of course not rigidly defined. Some may want to list the requirement that under repeated falls the bicycle pedals should not break as specification while some may call it a standard of performance.
- The some requirement can have two different roles under two different design conditions. The cost of a **car** may be specification if we are designing one for the middle-income group, but only a standard of performance if we are designing it for entering it in an automobile race.

Writing an accurate specification needs collection of information. For example, to determine the dimensions of a **blackboard**, data on human body dimensions are a must, to determine the range within which writing will take place from top to bottom. Height of blackboard equals

difference between highest reach of shortest man and lowest reach of tallest man The term shortest and tallest cover 97% of human population Width of blackboard will be decided from the size of the lecture hall.

While writing down specifications, the following points should be kept in mind.

(*i*) Reliability (*ii*) Safety
(*iii*) Ease of use (*iv*) Cost
(*v*) Ease of maintenance.

Q. 2.23. Explain briefly 'Product Design Specification' (PDS).

Ans. The **product design specification** is a *detailed listing of the requirements to be met to produce a successful product or process.* **Specifications** *are the formal means of communication between the buyer and the seller* For the usual product, the buyer is the customer and the seller is the design/manufacturing team and specifications are internal to the producing company

A PDS is a document which contains all of the facts related to the product outcome The PDS is the basic reference source of the design activity.

The twenty eight primary elements that go into the PDS are ·

1 Performance	2 Environment
3 Service life	4 Maintenance
5 Target product cost	6 Competition
7 Shipping	8. Packing
9 Quantity	10 Manufacturing facility
11 Size	12 Weight
13 Aesthetics, appearance and finish	14 Materials
15. Product's life span	16 Standards and specifications
17 Ergonomics	18. Customer
19 Quality and reliability	20. Shelf life in storage
21. In-house processes	22. Design schedule
23 Testing and inspection	24 Safety
25. Company constraints	26 Market constraints
27 Patents	28. Social and political factors

- *Whenever possible the specification should be expressed in quantitative terms and when appropriate it should give limits within which acceptable performance lies*

Q. 2.24. You are given a product design to test its economic feasibility. Explain how you will carry out this test.

Ans. Economic feasibility. *The economic feasibility of a design is best measured by its utility factor*

Cost factor alone is not a measure of economic worth. For a single product, a financial feasibility is essential

Financial feasibility. The financial feasibility is calculated on the basis of 'Net present value' For example, if Rs. P. are to be invested today in a design project which for n years will yield R every year, then *it is feasible to go in for the product if*

$$P < R\left[\frac{1-(1+r)^{-n}}{r}\right]$$

where, r is the cost of capital (in percentage).

Example. The initial investment for a project is Rs. 20,000. Return per year is Rs. 9,000 for 3 years. Check the financial feasibility if the cost of capital is 10%.

Solution. Initial investment, P = Rs. 20,000

$$\text{Return} = 9{,}000\left[\frac{1-(1+0.1)^{-3}}{0.1}\right] = 9{,}000\left(\frac{1-0.7513}{0.1}\right) = \text{Rs. } 22{,}383$$

Thus net gain = 22,383 – 20,000 = Rs. 2,383

Thus the project is *financially viable.*

HIGHLIGHTS

1. *Production design* is concerned with design of some appliances, systems components, and other similar unit-type items, for which there appears to be market.
2. The requirements of a good product design are :
   (*i*) Customer satisfaction;
   (*ii*) An adequate profit.
3. The following factors affect product design:
   (*i*) Technical factors.
   (*ii*) Industrial design factors.
   (*iii*) Designing for production—Economic factors.
4. The following factors should be considered during product design:
   (*i*) Product variety versus standardisation
   (*ii*) Modularisation
   (*iii*) Design simplification.
5. A *product* is something sold by the enterprise to its customers and *product development* is the set of activities beginning with the perception of a market opportunity and entry in the production, sale and delivery of a product.
6. The following functions are central to a product development project:
   (*i*) Marketing.
   (*ii*) Design.
   (*iii*) Manufacturing.
7. A *product development process* is the sequence of steps or activities that an enterprise employs to conceive, design and commercialize a product.
8. *Specification* is defined as detailed description of the required characteristics of a device, equipment, system or process.
9. The product design specification (PDS) is the basic reference source of design activity.

10 *Standards of performance* are a set of broad requirements that cover a wide field which may include reliability level, safety, convenience in use, adaptability under various conditions, ease of maintenance and cost.

OBJECTIVE TYPE QUESTIONS

Fill in the Blanks or Say 'Yes' or 'No' :

1 .. .. product design includes not only the design of an item, but the testing, manufacture, and distribution of the product as well

2 The design phase of a product to be sold in the market ends only when the item has received wide acceptance by the public.

3 A .... design problem involves the interaction of numerous components that together form an operating unit.

4 The ultimate success of design is judged on the basis of its acceptability in the market place and how well it satisfies the needs of a particular culture

5 The product cost can be reduced if better mutual understanding exists between the ... . department and the . .. . division.

6 The design of the product should be complex

7. .... attempts reduction in variety and better use of productive facilities, thereby achieving lower unit costs.

8. .... is technique employed to obtain variety or perceived variety and yet hold down the cost.

9. A .... is something sold by the enterprise to its customers.

10. .... is defined as detailed description of the required characteristics of a device, equipment, system or process.

ANSWERS

1 Total	2 Yes	3 system
4 Yes	5. design, manufacturing	6 No
7 Standardisation	8. Modularisation	9. product
10 Specification.		

THEORETICAL QUESTIONS

1 What is 'product design'? Explain.

2 What do you understand by 'Total process design'?

3 What is 'system design'?

4. What is the effect of product design on the process design?

5 What are the components of the product cost? Explain

6. List the requirements of a good product design.

7. Explain briefly the various factors which affect product design

8 Describe briefly the following factors which should be considered during product design:

(i) Product variety versus standardisation.

(*ii*) Modularisation.
(*iii*) Design simplification.

9. Define the following terms:
(*i*) Product;
(*ii*) Product development.

10. Explain briefly the following terms which are central to a product development project:
(*i*) Marketing.
(*ii*) Design.
(*iii*) Manufacturing.

11 Enumerates the reasons for which a well defined development process is required/needed.

12. List the six phases of a generic product development process.

13. Define the term 'specification'.

14. What points should be considered while preparing the product specification?

15. List the various deficiencies of any specification.

16. Explain briefly the following:
(*i*) Technical specification.
(*ii*) Process specification.
(*iii*) Product specification.

17. Write a short note on "Standard specifications".

18. What is 'Product design specification'? List the elements which go into product specification.

19 What do you mean by 'Standard of performance'? Explain.

❏❏

3

Design Concepts

3.1. INTRODUCTION

- The term **'Design Concept'** *signifies the validity of the design idea.* The validity comes only after selecting the best solution, preparing a suitable model and testing it thoroughly to conclusively establish it that all the basic needs for which design was planned, are being fully implemented.
- **Concept Design** *is generally expressed as a sketch or rough three dimensional model and is often accompanied by a brief texturial description.* The degree to which a product satisfies customers and can successfully be commercialized is largely dependent upon conceptual design or concept of the product.

3.2. CONCEPT GENERATION

The concept generation is quite inexpensive and can be done relatively quicker in comparison to the rest of the developmental activities. It typically consumes 5 percent of the budget and 15 percent of development time in development efforts as this activity is not costly.

Concept generation process begins with a set of customer needs and target specifications and results in a set of product concepts design from which the team will make the final selection. In most of the cases an effective development team will generate huge number of concepts of which 5 to 20 will only merit serious consideration during the concept selection activity

The *concept operation methodology* involves the following *five steps* :

1. **Classify the problem :**
   - Understanding
   - Problem decomposition
   - Focus on critical sub-problems.
2. **Search externally :**
   - Lead users
   - Experts
   - Patents
   - Literature
   - Bench marking.
3. **Search internally :**
   - Individual
   - Group.
4. **Explore systematically :**
   - Classification tree
   - Combination tree.
5. **Reflect on the results and the process :**
   - Contructive feedback.

3.3. CONCEPT SELECTION

Concept selection *is the process of evaluating concepts with respect to customer needs and other criteria comparing the relative strengths and weakness of the concepts, and selecting one or more concepts for further investigation, testing or final development.*

"*Concept Selection*" is the process of narrowing the concept alternatives under consideration. Although this concept is a convergent process, it is frequently iterative and may not produce a dominant concept immediately.

In order to manage complexity of evaluating dozen of product concepts, concept selection is often done in *two stages*, namely ·

(*i*) Concept screening;
(*ii*) Concept scoring.

(*i*) **Concept screening.** Concept screening technique is a methodology, developed by Prof. Pugh, *to minimise the possibility of wrong choice of a concept;* the following "*basic rules*" are followed :

1. All ideas and early stages solutions must be *relevant to produce design specifications, i e*, they are solutions to the same problem having the same requirements and constraints
2. A concept evaluation matrix is established which *compares the generated design concepts against the criteria for evaluation.*
3. The criteria against which the concepts will be evaluated are *chosen from the detailed requirements of the 'Product Development Specification'*(PDS)
4. A reference or datum is chosen with which all other concepts will be compared. An existing design in the product area is *selected as the first datum choice*
5. Each concept/criteria combination is evaluated against the chosen datum by the following symbols
   + this indicates better than, less than, prone to act relative to datum
   – Indicates worse than, more expensive than, more difficult to develop than, more complex etc.

   S Indicates same as datum Use this when there is any doubt as to whether a concept is better or worse than the datum
6. Scores achieved by individual concepts are examined. If certain concepts show *unusually high scores they are accepted as best concepts.*
7. In case one or more strong concepts do not emerge, *change the datum and re-evaluate* If strong concept still does not emerge it means that the criteria are ambiguous.
8. If one concept continues to remain the strongest, change the datum and repeat If the same concept continues to predominate, let this strong concept be the datum
9. As strong and weak features of each concept emerge, it is required to attempt the changes that will improve the situation, often a new concept will emerge.

(*ii*) **Concept scoring.** This is used when development team feels that a well thought resolution will better differentiate among competitive concepts. Concept scoring can be avoided if team can comfortably select the concept through screening process.

3.4. QUALIFYING DESIGN CONCEPT

A **Design concept** *can be qualified only after selecting the best solution, preparing a suitable model and testing it thoroughly to establish that all the basic needs for which design was initiated are being fully complied.*

The following types of tests are usually used to qualify design concepts :

1. **Scale model tests.** These tests (performed on *reduced size part*) are used :
   - To evaluate new concepts;
   - To gain insights;
   - To determine feasibility.
2. **Development tests.** These are used for *verifying design concept* and follow iterative process, i.e., learning from failures and building on successes.
3. **Prototype tests.** These tests (performed on *full-size* preproduction items) are used to *investigate the workability of design prior to taking up commercial production.*

4. **Proof tests.** Several advanced proto-type items are tested to examine the degree of variability and also to identify the failure modes and weak links in the design. These provide important data for design verification.
5. **Acceptance tests.** These tests include 'Non-destructive tests' conducted on final production product to demonstrate that the product meets the design requirements within expected operating envelope. This type of test is a direct effort to verify the design.
6. **Model test.** In this case, a specified number of test articles are subjected to a rigorous series of tests to demonstrate the adequacy of design.

3.5. INFONOMICS IN ENGINEERING DESIGN

3.5.1. General Aspects

Infonomics *is a method of collecting, organising, analysing and transforming information.* It is the responsibility of the designer to transform incomplete information into useful, and complete information.

Effectiveness of any information depends on the limiting and correctness of the information presented because Engineer's decision is based on this information. An engineer presents information in the form of *graph, charts, specifications, statements, performance prediction, bill of materials, technical advice etc.*

3.5.2. Inputs for Infonomics in Engineering Design

Few of the inputs for Engineering design information system are enumerated and briefly discussed below :

(*i*) Market research information.
(*ii*) Product design test data.
(*iii*) Information on purchased parts and materials.
(*iv*) Information on field performance data.

(*i*) **Market research information :**

- This information provides the designer regarding the customer's opinions on the product and service being provided.
- It also provides the results of customer's experience which suggest opportunities for improving fitness for use.

(*ii*) **Product design test data.** This information provides the designer the data on parts and components under consideration.

(*iii*) **Information on purchased parts and materials.** This information provides the feedback in the following :

- Education of design for quality through minutes of design review meetings.
- Reliability predictions etc.

(*iv*) **Information on field performance data.** This information provides the designer the data of the products' performance on field.

3.5.3. Classification of Information

Information may be *classified* as follows .

1. **Information needs for planning :**
   - Environmental information
   - Competitive information.
   - Internal information
2. **Information needs for controlling the cost factors :**
   - Availability of material
   - Suitability of material.
3. **Hard information :**
   - Engineering basic principles,
   - Laws;
   - Quantities;
   - Standards;
   - Data on present systems;
   - Drawings etc.
4. **Soft information :**
   - Opinions,
   - Ideas;
   - Proposals;
   - Situations;
   - Projected data on future demand of product etc.

3.5.4. Sources of Information

The designer has to continually work for various sources of information for :

—Updating his data;

—Updating his project work;

—Collection of information on similar work;

—Experience of established engineer;

—Latest trends in 'Engineering design' etc.

The *various sources of information are :*

1. Literature published by suppliers of materials and equipment.
2. Associations in the respective field.
3. Testing and Research organisations.
4. Discussions with professional consultants.
5. Technical reports published by Government sponsored R&D.
6. Dealers and customers.
7. Company reports.

8. Patents.
9. Handbooks.
10. In-house experts.

- Collecting information from various sources is an art and requires time and money. All engineering information thus has an *economic base.*

3.5.5. Methods of Obtaining Information

The different methods by which information is obtained are as follows :

(*i*) Market survey.
(*ii*) Statistical sampling.
(*iii*) Questionnaire.
(*iv*) Personal interview.
(*v*) Observation.
(*vi*) Case study.

Some Important tips when asking questions from the people are

- Prepare the questions before going for the conversation/interview
- Identify yourself, your work and its purpose.
- Be specific, in asking questions
- Atmosphere should be free and frank.

An important point to realize is that the information needed in design is different from that usually associated with an academic course. The need often is for more specific and current information. Identify the needed pieces of information and find or develop that information.

3.5.6. Problems Encountered in Collecting Information

Following are the *problems* generally encountered in collecting information :

1. Where can I find the source of information?
2. Where to locate the information and its availability?
3. How to get the desired information?
4. How credible and accurate is the information?
5. What type of information is needed?
6. How to interpret the information for my specific need?
7. Whether the information collected is sufficient or not?
9. What inferences can be drawn from the information?

3.5.7 . Points to be Considered in Reporting a Design

The following points should be considered in *reporting a design* :

1. A designer shall report on a logical framework using a progressive argument.
2. As far as possible, use of present tense must be made.
3. Provide information on a comprehensive way so that other persons can take over the balance work from any stage.

4 Tables and expressions must be laid out in a clear and tidy fashion, defining every symbol and unit used.
5 A summary of main ideas be included and outlined in a simplified and understandable manner
6. Design sheets, design tabulations, graphs and sketches, should be included and these should be as self-evident as possible and include the essential background.
7. Do not labour the obvious but give all the facts
8 Important ideas considered but discarded may also be included with reasons in reporting

3.6. DESCRIPTION OF PROCEDURES

Any design project involves a countless items, which can be given due importance only by following a logical development process In any project, end results are achieved only when all the associated sub-systems, components and parts work properly *For overall success, the engineering must be broken into smaller units and a description of procedures developed to organise the smaller units of engineering work*

Unsolved needs are called **problems** and solution to problem situations are arrived at by thorough understanding and not by superficial or fortuitous fitting of a few facts together or by the substitution of some numbers into a formula.

The following ***steps*** are involved in *solving a problem*

1. **Design process.** The various steps involved can be .
   - Analysis
   - Synthesis
   - Evaluation
   - Decision
   - Optimisation
   - Revision
   - Implementation
2. **Thought process :**
   - Preparation
   - Incubation
   - Overall consideration and penetration
   - Elaboration.
3. **Professional method :**
   - Problem definition
   - Plan treatment
   - Execute plan
   - Check as a whole
   - Learn and generalise.
4. **Problem solving :**
   - Recognition
   - Definition
   - Preparation
   - Analysis
   - Synthesis
   - Evaluation
   - Presentation.

5. **Scientific method :**
   - Collect existing facts
   - Prepare list of missing facts.
   - Develop hypothesis.
   - Design and conduct experiment.
   - Revise hypothesis.
   - Develop theories and validate them.
6. **Other approaches :**
   - Recognise and gather data.
   - List possible solutions and test them.
   - Select best possible solution and application

3.7. MORPHOLOGY OF DESIGN

The **morphology** *of design engineering deals in structural designing based on realistic assessment and field requirements*

The attitude of the designer changes from phase to phase. During feasibility study stage, he explores widely and makes only rough checks on cost and performance. In the preliminary design phase, he selects the group of ideas which fit together in a best way. He establishes the necessary sizes and other relationship with an attempt to predict performance He proceeds carefully to weed out the inaccuracies and the less valuable alternatives During detail design stage, all details are considered thoroughly. Every number, every dimension and every material specification is checked thoroughly. Time and cost are both important and cannot be over-looked.

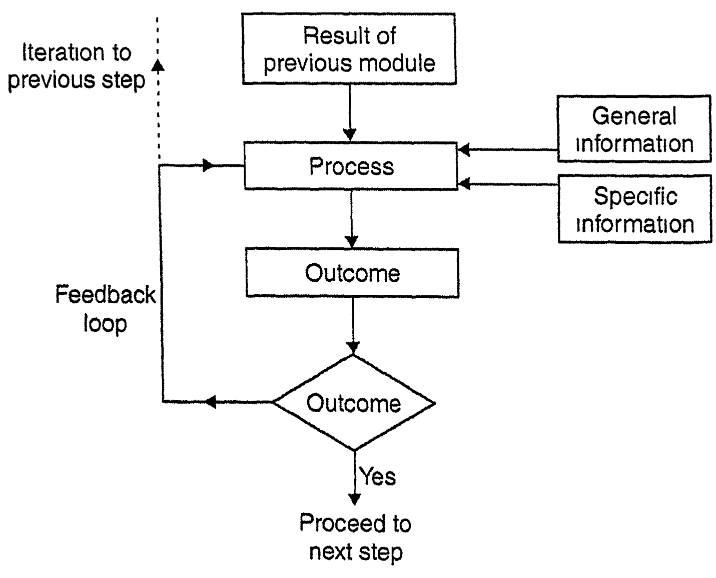


Fig. 3.1. Repeated graphic module used in various stages of morphology of design.

The **design process** *is the transformation of input information into integrated useful output information* **Evaluation** *is the review and decision process by which the effectiveness of the step is adjudged acceptable or not* If the result is *'yes'*, then one proceeds to next step, if *'not'* there is *need for further efforts or more information is necessary* The iterative return process is repeated as often as necessary to yield a 'yes' result finally at evaluation. The evaluation can be done either by making a mathematical model, or by a logic and common sense, if it is costly or impractical to make mathematical model due to insufficient knowledge.

Fig 3 1 shows the repeated graphic module used in various stages of "morphology of design". **Morphology of design** *refers to the following phases* ·

- *Phase – I* . **Feasibility study**
  — This stage is sometimes called *conceptual design*
- *Phase – II* : **Preliminary design**
  — This design stage is often called *embodiment state* It may also be called the experimental stage, since it involves building and testing experimental models
- *Phase – III* : **Detail design**
  — Phases I, II and III carry the design from the realm of possibility to probability to the real world of practicability; they constitute the *primary design*
- *Phase – IV* : **Planning for manufacture**
- *Phase – V* : **Planning for distribution**
  — The economic success of the design often depends on the skill exercised in marketing the product. If the product is of the consumer type, the marketing effort is concentrated on the advertising and news media techniques but highly technical products may require that the marketing step be a technical activity supported by specialized sales brochures and performance test data
- *Phase – VI* : **Planning for use**
  – An important phase VI activity is the acquisition of reliable data on failures, service lines and consumer complaints and attitudes to provide a basis for product improvement in the next design.
- *Phase – VII* · **Planning for retirement of the product.**

3.8. BRAINSTORMING

3.8.1 General Aspects

Brainstorming *is an idea generating approach that is used to find problems, causes of problems, causes of variation, ways to prevent problems, solution to problems or ways to implement these solutions.*

"Brainstorming" is a conference when group of people gather and discuss to arrive at a solution for a particular problem The number of participants may vary from two to hundred.

The following are the essential *requirements* of brainstorming :

- Group should be composed of persons with experience in the area of problem.
- All persons in the group should be of *same status* so as to allow free discussion.
- Members should feel free to *give any idea without fear.*
- An agenda is to be prepared and is to be circulated to all members of the group in advance, so that members can *generate ideas for discussion.*
- The session should be held in *an informal and comfortable atmosphere.*
- All ideas discussed during the session should be *recorded and distributed to participants afterwards*

The new ideas developed are the main factors for emphasizing that brainstorming is a *group technique.* Ideally, brainstorming has a synergistic effect; group elements generate new ideas as a group than they would merely by aggregating their individual lists

Brainstorming can be viewed as having the following phases

(*i*) Idea-generation phase
(*ii*) Idea-evaluation phase.

If brainstorming is to be as successful as possible, evaluation on *criticism of any idea should not be allowed during the idea-generation phase* Such criticism could inhibit some one from suggesting an idea for the fear that it may sound dumb. An idea that sounds dumb at first could end up, after careful thought, contributing to the solution.

3.8.2. Brainstorming Techniques

Following are the *rules for* **creative techniques :**

(*i*) Do not attempt generating new ideas and judge them at the same time and let them be separated by time space and people if possible.
(*ii*) Generate large quantity of possible solutions Multiply the ideas produced first by inspiration by 5 or even 10.
(*iii*) Seek a broad spectrum attack approach.
(*iv*) Watch for opportunities to combine or improve ideas as they are generated
(*v*) Consider all possible ideas even apparently impractical. Do not ridicule them. Never eliminate any ideas summarily

The various creative techniques are discussed below :

1. Osborn's brainstorming technique :

- This problem-solving technique is based on stimulation of one person's mind by mind of another.
- An average group consists of 4-5 persons, who sit around a table and simultaneously produce ideas designed to solve a problem.

Following *rules are followed* :

(*i*) Criticism is ruled out.
(*ii*) Freewheeling is welcome.

(*iii*) Any number of ideas are welcome and desirable.
(*iv*) Combination and improvement are sought.

2. **Phillips buzz session technique.** This technique is useful in *developing creative ideas from large audience situations* It entails the following *procedure* ·
   - The audience is divided into a large number of groups of six people each.
   - Within each group, a leader and a recorder are appointed, they should be selected and briefed before the meeting, if possible.
   - The problem to be tackled is announced before the meeting gets started.
   - Using the group brainstorming method, each group develops creative alternatives.
   - After a period of time and a signal from the leader, each group stops producing ideas and begins evaluating the ideas and selecting the best solution
   - The leader of each group is called upon to present the ideas produced, so the rest of audience.

Thus, finally an effort is made to arrive at the best/optimum solution

3. **Crawford slipwriting technique.** This is another technique *specially suited to large audience*
   - It is a form of *individual brainstorming*
   - This technique provides many ideas for a wide range of different problems in one session. Each person in a large audience is given a coloured slip of paper on which he is asked to make a statement relating to the problem.

3.9. DECISION MAKING

3.9.1. General Aspects

A **decision** *is the conclusion of a process by which one chooses between two or more available alternative courses of action for the purpose of attaining goal, the process is* called **decision making.** A *'decision' represents a course of behaviour chosen from a number of possible alternatives*

The *importance of decision of making* is realised on account of following *reasons* :

(*i*) *To select the optimum solution.* Owing to the rapid advancement in technological fields, modern design problems have become quite complicated. Various alternative solutions are available for a design problem but the designer applies his creative mind to evolve the optimum one It is here that the proper technique of decision-making comes into play.

(*ii*) *Stress on better performance due to increased competition.* There is a growing competition of the products in the market with regard to their overall better performance. Once the operating parameters are varied slightly, it will surely reflect on its performance. Hence the importance of quick decision is felt by the designer.

- Decision making (an intellectual activity) is vital to all management activities. It helps .

  —To get definite objectives, —To prepare plans of action,
  —To determine organisational structure; —To motivate personnel;
  —To introduce innovations.

3.9.2. Types of Decisions

Some of the *important types of managerial decisions* are as follows :

1. Programmed and non-programmed decisions
2. Major and minor decisions.
3. Routine and strategic decisions.
4. Organisational and personal decisions.
5. Individual and group decisions.
6. Policy and operative decisions
7. Long-term, departmental and non-economic decisions.

1. Programmed and non-programmed decisions :

- ***Programmed decisions*** are *those decisions which are made in accordance with some habit, rule or procedure.* The policies, rules or procedures by which we make decisions free us of the time needed to work out new solutions to old problems, thus allowing us to devote attention to other, more important activities in organisation

- ***Non-programmed decisions*** are *those decisions that deal with unusual or exceptional problems* (such problems as "How to allocate an organisation's resource", "What to do about a failing product line" etc.)

2. Major and minor decisions: A decision related to the purchase of a CNC machine costing several lacs is a *major decision* while the purchase of a few reams of typing paper is a *minor decision*.

3. Routine and strategic decisions :

- ***Routine decisions*** are of repetitive nature, do not require much analysis and evaluation, are in the context of day-to-day operations of the enterprise and can be made quickly at *middle management level.*
  Example · Despatch of samples of a food product to the Government investigation centre.
- ***Strategic decisions*** *relate to policy matter* These decisions are taken at *higher levels of management*, after careful analysis and evaluation of various alternatives.
  Examples Decisions related to pricing, expansion and change in product line etc

4. Organisational and personal decisions :

- ***Organisational decisions*** reflect the basic policy of the company They can be delegated to others.
- ***Personal decisions*** cannot be delegated.

5. Individual and group decisions :

- ***Individual decisions*** are taken by a single individual in context of routine decisions, where guidelines are readily provided.
- ***Group decisions*** are taken by a committee constituted for this specific purpose.

6. **Policy and operative decisions :**
   - ***Policy decisions*** mostly relate to basic policies They are very important and taken by *top management.*
   - ***Operative decisions*** relate to day-to-day operations of the enterprise They are taken at *lower or middle management level*

     Example Whether to give bonus to employees is a policy decision but calculating bonus for each employee is an operative decision.
7. **Long-term, departmental and non-economic decisions :**
   - In case of *long term decisions*, the time period covered is long and the risk involved is more
   - *Departmental decisions* relate to factors such as technical values, moral behaviour etc

3.9.3. Theories of Decision Making

In decision-making, various alternatives are evaluated in the context of the organisational objectives For this evaluation purpose, normally following *three approaches* are considered

1 Marginal theory.
2 Mathematical theory.
3 Psychological theory.

1. **Marginal theory :**
   - This theory suggest by economists *emphasizes the maximisation of profit*
   - The profit is maximum where marginal costs of inputs are equal to marginal revenues from outputs Marginal cost is the additional cost which is incurred for taking one additional output Similarly, marginal revenue is earned by selling one additional unit of output. When marginal costs and revenues differ, the profit cannot be maximum because, in that case, either more additional revenues can be earned at less additional costs, or additional revenues earned would be less than additional costs In the first case, profit is maximised by additional output, and in the second case, it is maximised by reduction in output.
2. **Mathematical theory :**
   - This theory suggests the decision making ***through building mathematical models.*** This approach is *commonly used by large-sized organisations where decision making problem is very complex.*
   - The models are constructed taking all factors affecting a decision.

Various techniques such as venture analysis, game theory, probability theory, waiting theory, linear programming etc , are utilised for 'decision model building'

3. **Psychological theory :**
   - The marginal and mathematical theories *emphasise on maximisation or profits* which is the treatment of a manager as 'economic man'

- Somê hold the view that good organisations do not want profit maximisation, rather they want *maximisation of satisfaction*. Thus, manager is not an economic man, but an administrative man The former selects best alternative which combines various things The manager in the latter approach involves in finding out an alternative only when the profits go below the satisfactory level. The *satisfactory level may not be maximum profits*

3.9.4. Decision-Making Techniques

The different decision making techniques of 'Programmed' and 'Non-programmed decisions' are given below :

1. Programmed decisions. Routine, repetitive decisions — *Organisation develops specific processes for handling them*

Decision making techniques :

- *"Traditional"*
  - — Habit
  - — Clerical routine standard operating
  - — Organisational structures . Common expectations–A system of sub-goals – well defined information channels
- *"Modern"* .
  - — Operation research, Mathematical analysis, Models, Computer simulation
  - — Data processing

3. Non-programmed decisions Non-routine, one shot, ill structured, novel policy decisions — *Handled by general problem-solving processes* ·

Decision making techniques :

- *"Traditional"* .
  - — Judgement; intuition and creativity.
  - — Rule of thumb.
  - — Selection and training of executives.
- *"Modern"* :
  - — Heuristic problem solving technique is applied to :
    - (*i*) Training human decision makers, and
    - (*ii*) Constructing heuristic computer programs.

3.9.5. Specific Approach to Decision Process

The scientific approach (a formalized reasoning process) consists of the following *steps* ·

1. *Problem defined.* The problem for analysis is defined and the conditions for observation are determined.
2. *Observations made.* The observations are made under different conditions to determine the behaviour of the system containing the problem.

3. *Hypothesis postulated* Based on the observations, a hypothesis that describes how the factors involved are thought to interact or what is the best solution to the problem, is conceived
4. *Experiment designed.* To test the hypothesis, an experiment is designed
5. *Experiment executed* The experiment is executed and measurements are obtained and recorded
6. *Hypothesis accepted or rejected :* The results of the experiment are analysed and hypothesis is either accepted or rejected.

The above six steps of scientific method can be applied to decision making; for example, the *evaluation of alternatives is done scientifically through experimentation*

Fig. 3.2 shows the overall relationship of the scientific approach to the decision-making process.

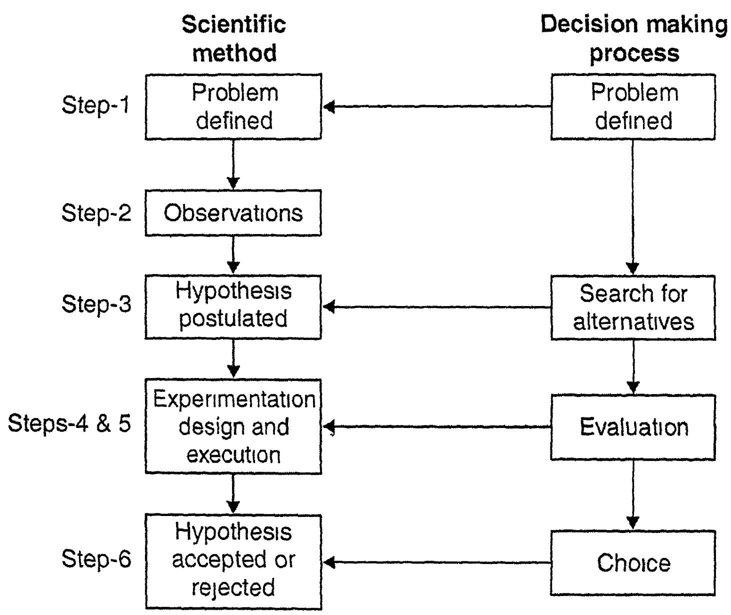


Fig. 3.2. Relationship of scientific approach to the decision making process.

3.9.6. Guidelines for Effective Decision Making

Following *guidelines* may be followed for effective decision-making :

1. To define the goals.
2. To ensure that the decision will contribute to the goal
3. To adopt a diagnostic approach to decision making.
4. To involve subordinates in decision making process.

5. To ensure successful implementation of the decision
6. To evaluate the results
7. To be flexible and revise the decision, which does not yield the observed results.

3.10 . PHYSICAL REALISABILITY

3.10.1. General Aspects

- The **physical realisability** *of alternative solution depends on an inter-relationship between several factors* To enable decision making, it is necessary to develop a theory of physical realisability that explics the effect of various factors to be considered. This is achieved by setting out two hypothesis, *one to develop the theory, and second to suggest as to which of the two criteria implied by theory is pertinent in a given design situation.*
- As the confidence is physical realisability of particular concept increases, and its concomitant advantages are comparable to the alternatives, it can be selected
- The *'intensity of belief'* that a physically realisable design can be accomplished with given money and time is one of the important factors to be considered in deciding the physical realisability. Such beliefs cannot be absolute and have some uncertainty until the task is almost accomplished, at which stage the belief becomes a fact. It is thus necessary to judge the level of confidence of belief. It is expressed as under .

$$\text{Confidence Level } L = f\left[E, R_B\left(\frac{dE}{dR}\right)\right]$$

where, E = Amount of favourable evidence in decimal,

R = Current expenditure in rupees and it may vary from O to R_B (allowed budged of time and money)

$\frac{dE}{dR}$ = Initial rate of increase in favourable evidence with expenditure, *a measure of traceability*

3.10.2. Hypothesis about Selection Criteria

The following two hypotheses about selection criteria can be used as conceptual instruments for gauging the level of confidence that a realisable design can be achieved within given budget.

Hypothesis–I. A rational decision rule is to select that design concept (out of various alternatives) which has the most favourable list of expected advantages and is judged to be reasonably certain of physical realisability. Whichever of three factors (*viz. prior evidence that a realisation can be achieved, cost of carrying out the design, or traceability*) contributes to confidence in physical realisability is the most significant. The relative importance of these three factors is pronounced by the second hypothesis

Hypothesis–II. During the stages of feasibility study, preliminary design, first part of detailed design, the traceability exerts more influence on the level of confidence, and it is thus the more important selection criterion. During the detailed design stage, the cost of producing a realisable design is the predominant criterion.

3.10.3. Process of Resolving Physical Realisability

While doing the analysis of any sub-problem, one comes across both favourable and unfavourable evidence to support the hypothesis that the concept can be resolved into a physically realisable design. Various possibilities are probed. Those which lead to unresolvable difficulties provide negative evidence, and others which *allow deeper penetration provide a final resolution of the problem.*

— If probing in a particular direction is unsuccessful, then reasons for same must be found and at such classes of directions, which would be unfavourable for similar reasons are eliminated. The favourable evidence is now distinguished from unfavourable by gauging the extent to which sub-problems are reasonable

- It is not only important to reach the goal, but to understand the process for reaching the goal. A designer *makes trials to reach the goal by avoiding repeated errors and seeking positive indications of realisability of solution, before going too far in a given direction*

3.11. NEW METHODS OF DESIGN

The following are some important *new methods of design*

1. **Systematic search.** The aim of this method is to solve the design problem with *logical certainty.*
2. **Value analysis.** The aim of this method is *to increase the rate at which designing and manufacturing organisation learn to reduce the cost of product*
3. **Systematic engineering.** The aim of this method is *to achieve internal compatibility between the components of a system and external compatibility between a system and its environment*
4. **Matchett's Fundamental Method (FDM).** The aim of this method is *to enable a designer to perceive and to control the pattern of his thoughts and to relate this pattern more closely to all aspects of a design solution.*
5. **Investigation User Behaviour.** The aim of this method is to explore the behaviour patterns and to predict the performance limits of potential users of a new design.
6. **Brainstorming.** The aim of this method is to *stimulate a group of people to produce many ideas quickly*
7. **Synectics.** The aim of this method is *to direct the spontaneous activity of the brain and the nervous system towards the exploration and transformation of design problem*
8. **Morphological charts.** The aim of this method is *to widen the area of search for solutions to a design problem*
9. **Interaction matrix.** The aim of this method is *to permit a systematic approach for connections between elements within a problem.*
10. **Functional innovation.** The aim of this method is *to find a radically new design, capable of creating new patterns of behaviour and demand.*
11. **Quirk's Reliability Index.** The aim of this method is *to enable experienced designers to identify unreliable components without testing*

3.12. DESIGN PROJECT–PHASES INVOLVED

In any design product, usually the following *stages* are involved :

1. Feasible study.
2. Preliminary design
3. Detailed design.
4. Production planning.
5. Distribution planning.
6. Consumption planning.
7. Retirement planning.

1. **Feasible study.** It provides a *set of useful solutions to a problem* Following *steps* are involved :
   - To demonstrate that the original need has current existence.
   - To explore the design problem and identify elements like parameters, constraints, major design criteria etc
   - To conceive a number of possible solutions.
   - To sort out potentially useful solutions on the basis of physical realisability, economic worthwhileness, and financial feasibility.
2. **Preliminary design.** It establishes the *best design concept.* The various *steps* involved are :
   - To subject each alternative solution to order of magnitude analyses, until one is proved to be best.
   - To initiate synthesis studies for establishing the fitness of the range within which the major design parameter must be controlled.
   - To investigate the tolerances in the characteristics of major components and critical materials to ensure mutual compatibility and proper fit into the system.
   - To examine the influence of environmental and internal forces on the stability of the system.
   - To study how the design will meet consumer's taste, how it will match with products of competitors, whether scarce and critical raw materials will continue to be available, rate of obsolescence.
   - To study the rate of deterioration of performance with corrosion, wear, fatigue, etc.
   - To test the critical aspects of the design in order to validate the design concept and provide information for subsequent phases.
3. **Detailed design.** *It furnishes the engineering description of a feasible design.* Various *steps* involved are :
   - To develop an overall, provision synthesis as a master-layout.
   - To prepare specifications of components.
   - To initiate experimental design-by constructing models to check out untried ideas.

- To test prototypes, and using information obtained as basis for redesign and refinement

4 **Production planning.** *It involves skill of tool design and production engineering* Following *steps* are involved

- Detailed planning of the manufacturing processes for all parts, sub-assemblies and final assembly
- Design of tools and fixtures.
- Planning, specifying or designing new production and plant facilities
- Planning for quality control
- Planning for production personnel—developing job specifications, estimating standard times and labour cost
- Planning for production control—To establish standard costs for labour, materials and services.
- Planning the information—flow system
- Financial planning

5. **Distribution planning.** *It is concerned with an effective and flexible system of distribution of the designed product* The various *steps* involved are

- Designing for packaging to take care of aesthetics, economy in transportation, to secure protection from shock and weather, to facilitate handling
- Planning the warehousing system
- To design technical sales brochures for promotional activity

6. **Consumption planning.** In order to have timely impact, the process of assumption must be anticipated in the early stages of design. Various *steps* for designing are

— Maintenance — Reliability
— Safety — Convenience in use
— Aesthetic features — Operational economy
— Adequate duration of service.

7. **Retirement planning.** The following points need consideration .

- Designing to reduce obsolescence rate.
- Designing physical life to match anticipated service life.
- Designing so that reusable materials and long-lived components can be recovered

3.13. MORPHOLOGICAL ANALYSIS

Morphological analysis *recognizes that the solution to a design problem consists of certain essential constituent parts and a good design is one which selects the proper "matching" combination of components*

It is based on the premise that novel designs can be created by treating most designs much like an electronic system, where a combination of stages represented by block diagrams are matched at the interface to give the required overall performance. Various solutions or blocks are then thought up for each part and these blocks are then recombined.

The *step-by-step procedure* is as follows .

1 Recognize the parameters essential to the design.
2. Determine a number of possible ways for achieving each of the parameters.
3. Set-up a chart of matrix in the left hand column on which are listed all the parameters and in the rows against each of these parameters are listed the possible methods of achieving them
4. Study all combinations of sub-solutions for feasibility and select the best on the basis of some valid criterion.

— It is almost a pre-requisite for this method that the essential blocks of the problems are stationary—the only freedom available is in the choice of what to use for each block. By the structure being stable we mean that there is a little doubt about what the essential parameters of the problem are

- This method is *usually straight forward in application.*

3.14. CREATIVE DESIGN

Creativity, *innovation* and *invention* are loosely synonymous terms meaning *the process of evolving a new device or process that can better solve some need of mankind*

The "*creative process*" can be viewed as *moving from an amorphous idea to a well structured idea, from the chaotic to the organised, from the implicit to the explicit.*

Following positive steps enhance the *creative thinking* :

(*i*) Develop a creative attitude.
(*ii*) Unlock your imagination.
(*iii*) Be persistent.
(*iv*) Develop an open mind.
(*v*) Suspend your judgement.
(*vi*) Set problem boundaries.

Creative design routes. The creative design routes are practiced by adapting the following sequence :

1. ***Preparation.*** Analysing the need and collection of all the information required at various stages.
2. ***Concentration.*** Disgestion of all aspects of the problem situation.
3. ***Incubation.*** Relaxation away from problem for sometime.
4. ***Illumination.*** A rush of insight, relief and understanding of a solution.
5. ***Verification.*** Testing and inspection, and completion of details.

- *The qualities and factors for a creative designer are* ·

(*i*) Be perceptive.
(*ii*) Try to get rid of fixity of mind.
(*iii*) Plan solution with inventive process in mind.

(*iv*) Use techniques of brainstorming and synectics
(*v*) Try inversion methods (*i e* , imagine the reverse of existing way like upside down, inside out etc)
(*vi*) Use analogy (*i e* , get hints from proven solutions for similar problems).
(*vii*) Use empathy (*i e* , put yourself in other position, or imagine being part of object)
(*viii*) Use fantasy (*i e.*, dream fanciful solutions based on unreal or supernatural process)
(*ix*) Adopt a systematic search for new combinations.

3.15. UTILITY DESIGN

Characteristics of good design. The *characteristics of good design are*

1 Low cost
2 High accuracy.
3 Attractive appearance
4 Reliability.
5. Simplicity.
6. Trouble free operation.
7 Long useful life.
8. Low maintenance and noise level.

Steps involved in designing a product. *Following steps are involved in designing a product* :

1. To perform analysis of requirements
2. To define the scope, objectives and pertinent restraints with respect to the requirements; identify any significant problem to be solved.
3. To develop alternative solutions.
4. To perform feasibility analysis of alternative solutions
5 To optimise the promising solutions
6. To select the best solution
7 To implement the solution

Utility design process. The various *steps* associated with design process are :

1. Need recognition.
2. Problem definition
3. Preparation and information collection
4. Task specifications.
5. Idea generation.
6. Conceptualisation.
7. Analytical and experimental stage
8. Design synthesis.
9. Evaluation
10. Optimisation.
11. Presentation.

3.16. PROBABILISTIC DESIGN

To design is to formulate a plan for the fulfilment of a human need Having established the need, the *design could be based on the theory of probability or a deterministic assumptions*

In "*probabilistic design approach*", attempts are made to optimise design solutions to achieve important objectives. The probability of adequate performance can be estimated by having knowledge of failure theories, stress analysis and dynamic behaviour of materials

Recent concern with the reliability of designed mechanical products has lead to re-evaluation of the foundation of design The *awareness for reliability concept has resulted in*

— Development of *finite element analysis* (defining stress),
— *Fatigue research* (material behaviour and physics of failure);
— Development of *fracture mechanics* (crack propagation and failure),
— Development of *probabilistic design* (close correspondence between predicted and actual performance of mechanical components),
— *Optimisation* (Improvement in efficiency and economy)

- *The **objective** of "probabilistic design" is to create systems that satisfy operational and economic requirements with a specified measure of reliability* The following *aspects* need consideration in this regard
  — Preliminary design concept looked for a solution in accordance with anticipated usage and subject to change, as economic and operational considerations get understood
  — Loads to be imposed/resisted must be quantitatively estimated The idea of range of magnitudes and relative frequency is required.
  — From an analysis of the preliminary system, quantitative descriptions of loads in the individual components can be estimated
  — The selection of material and heat treatment etc. must be on the basis of mechanical and/or physical properties, purpose of design, limitations imposed by economics and feasibility.
  — Statistical descriptions of the significant strength characteristics of the materials must be obtained.
  — A quantitative description of the strength or resistance properties and the failure characteristics of each individual element must be estimated.
  — A description of the collective strength and failure characteristics of the system of elements must be estimated.

The system thus described may be optimised in relation to operational demands and economic constraints.

- The probabilistic theory admits a small probability of failure (consistent with experience), treats strength and stress as multi-valued phenomenon (consistent with test and measurement result), and depends on statistical members for modelling variables and statistical algebra for constructing functions.

Functions of design variables are treated as functional relationships among random variables, each having a defining probability density function. The model of the function is also a multivariate probability density function.

3.17. VALUE ANALYSIS (VA) AND VALUE ENGINEERING (VE)

Value analysis (VA) : *It is an organised procedure for efficient identification and elimination of unnecessary costs* The ***aim*** of *"value analysis" is to provide the stated function, desired quality, prescribed specification or the required degree of customer appeal of any product at that least cost*

Value analysis is basically a *cost reduction technique.* It is not a technology in itself but a logical organised method of applying various technologies or techniques to the solution of value problems

The term 'value' is commonly associated with worth, price or cost, but has a different connotation when applied in value namely, economic value, moral value, aesthetic value, social value, political value, religious value and judicial value Of these only *"economic value"* can be considered objectively or measured, the remainder can only be evaluated subjectively. Economic value can be further sub-divided into the following four categories :

(*i*) Functional or use value.
(*ii*) Cost value.
(*iii*) Esteem value.
(*iv*) Exchange value.

Value analysis includes the following *steps*

1. To appoint an advisor or group to teach value analysis to inter-departmental teams and to monitor their progress.
2 To establish defined standards for product performance and quality.
3. To make detailed records of the cost of all manufacturing operations and purchases
4 To set each inter-departmental team to carry out the following four stages of value analysis for each physical component of a product ·
   (*i*) *Identification* of elements, functions, costs and values.
   (*ii*) *Search* for alternatives at lower costs.
   (*iii*) *Selection* of functionally acceptable lower cost elements.
   (*iv*) *Presentation* of the selected redesign
5. To submit the result of value analysis to the value analysis advisors, the engineering design group, and the management for approval prior to production of lower cost design.

Value Engineering (VE) ***"Value engineering"*** *is the application of the concepts of value analysis at the design stage of the component parts with an idea of cutting down the unnecessary costs, without affecting the quality of the product.* Value engineering got developed because of the inherent desire of human being to make cheaper product, keeping the utility of the product same.

- **"Value engineering"** *is normally used in relation to design of new products* and **"Value analysis"** is normally *used in relation to existing products.*

3.18. COSTS IN MANUFACTURING

Manufacturing costs can be divided into two major categories : *Fixed costs* and *Variable costs* The difference between the two is based on whether the expenses vary in relation to the level of output

Fixed cost. A fixed cost is one that is *constant for any level of production output.*

Examples. Cost of *factory building, insurance, property taxes, and the cost of production equipment.*

—All of these can be expressed as annual costs

Variable cost. The variable cost is the one that *increases as the level of production increases.*

Examples. Direct labour costs, raw materials, and electrical power to operate the production machines etc.

—The ideal concept of variable cost is that it is *directly proportional to output level.*

Overhead costs. Overhead costs are all the other costs associated with running a manufacturing firm Overhead can be divided into two categories ; *Factory overhead* and *Corporate overhead.*

"Factory overhead" includes the cost of operating the factory other than direct labour and materials.

"Corporate overhead" cost is the cost of running the company other than its manufacturing activities.

QUESTIONS WITH ANSWERS

Q. 3.1. Describe briefly the basic module in the design process.

Ans. Fig. 3.3 shows the basic module in the design process (as described by *"Morris Asimow"*).

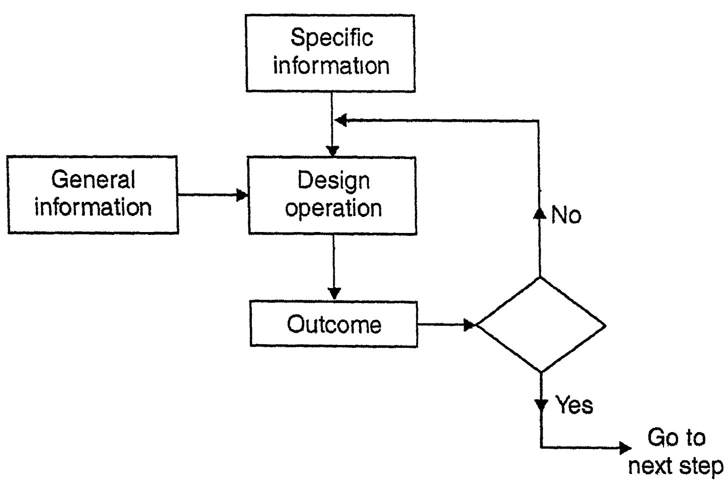


Fig. 3.3. Basic module in design process.

Design *is a sequential process*, and many consists of the following operations .

(*i*) *"Exploring"* the alternative systems which could specify the specific need

(*ii*) *"Formulating"* a mathematical model of the best system concept

(*iii*) *"Specifying"* specific parts to construct a component of a sub-system

(*iv*) *"Selecting"* a material from which parts are to be manufactured

The *design process* basically consists of the following *steps*

- Recognition of a need
- Definition of a problem.
- Gathering of information
- Conceptualisation.
- Evaluation.
- Communication of the design

Q. 3.2. Describe how design process depends on need analysis?

Ans. Fig 3 4 shows that how need analysis triggers the other elements of design process.

Structure and morphology of design

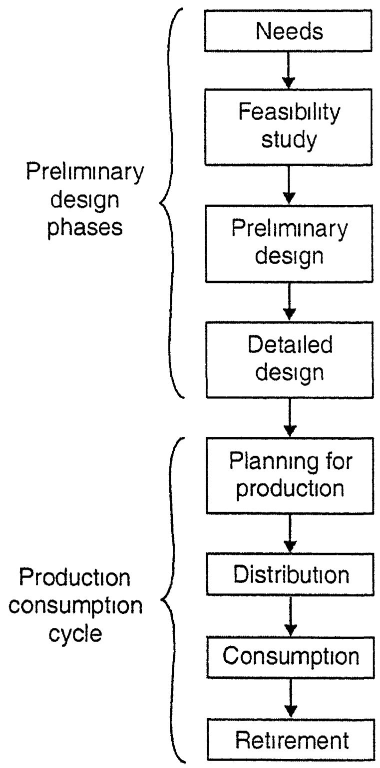


Fig. 3.4.

Q. 3.3. Order the following concepts used in design in a chronological structure and prepare a graphic form of design morphology.

(*i*) **Detail design;**
(*ii*) **Distribution;**
(*iii*) **Analysis;**
(*iv*) **Manufacture;**
(*v*) **Feasibility study;**
(*vi*) **Need;**
(*vii*) **Alternative design;**
(*viii*) **Production planning;**
(*ix*) **Consumer feedback;**
(*x*) **Marketing.**

Ans. The order is as follows :

(*i*) Need,
(*ii*) Feasibility study;
(*iii*) Analysis;
(*iv*) Alternative design;
(*v*) Detail design;
(*vi*) Production planning;
(*vii*) Manufacture;
(*viii*) Marketing,
(*ix*) Distribution,
(*x*) Consumer feedback.

The **flow diagram** *showing sequence* of activities in the design morphology of a product is exhibited in Fig. 3.5.

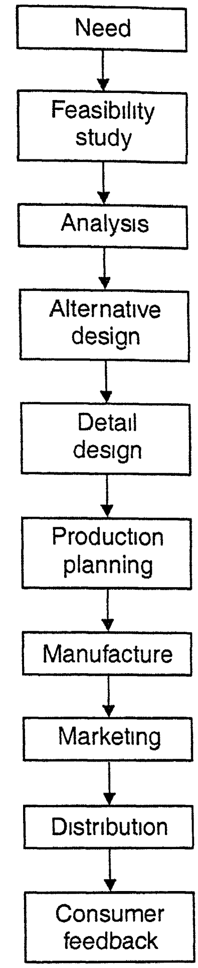


Fig. 3.5. Flow Diagram showing sequence of activities in the design morphology of a product.

Q. 3.4. Give the typical steps in the design of a new product.

Ans. Fig. 3.5 shows the typical steps in the design of a new product.

In Fig. 3.6, the reader should be able to recognise the steps in the design process. It may be noted that how information flows from design analysis, prototype testing and product performance in the field can be used to improve the product.

In modern design practice many of the design steps are facilitated by the use of computers (Computer Aided Design–CAD) and there is a growing use of computer controlled machine tools (Computer-Aided Manufacturing–CAM). The link between these two functions is the design database in digital form.

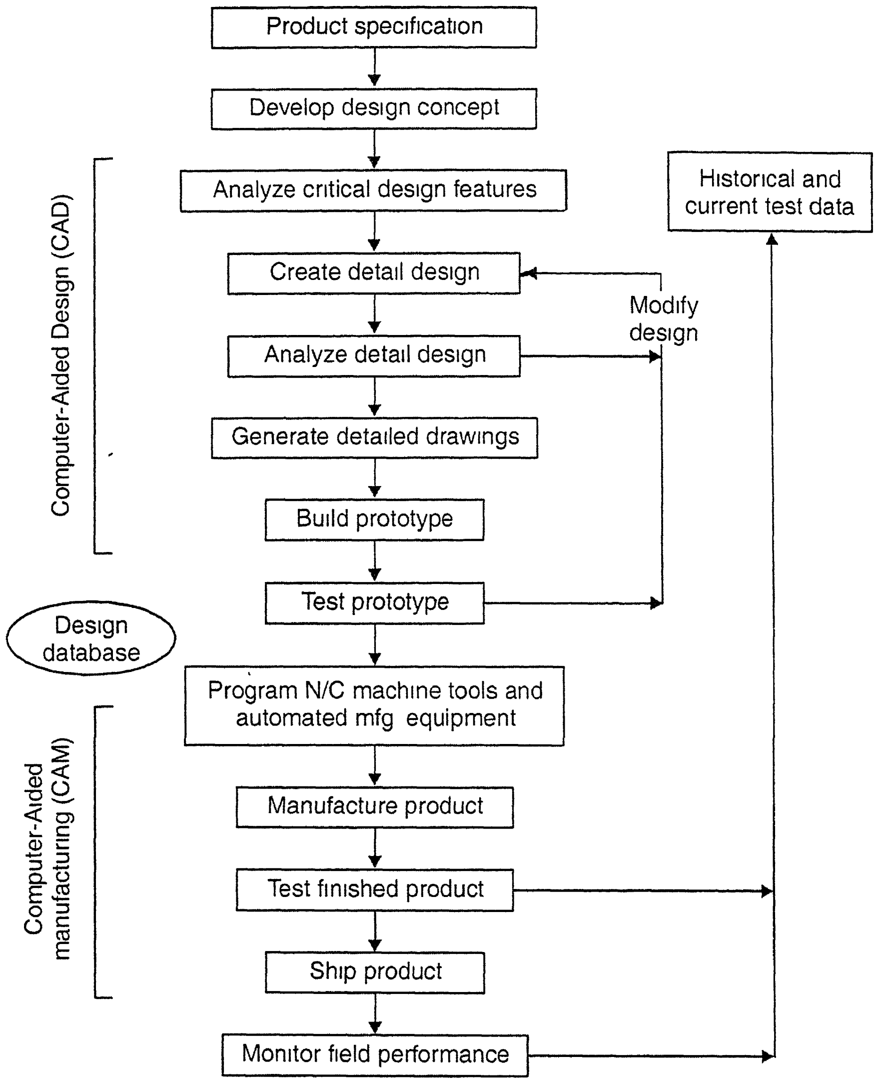


Fig. 3.6. Typical steps in the design of a new product.

Q. 3.5. Explain briefly the "Evolution process of a new product".

Ans. The cycle followed during the process of evolution of a new product is shown in Fig. 3.7, which shows the *sequence of events necessary to convert the original concept to the point of production and marketing*

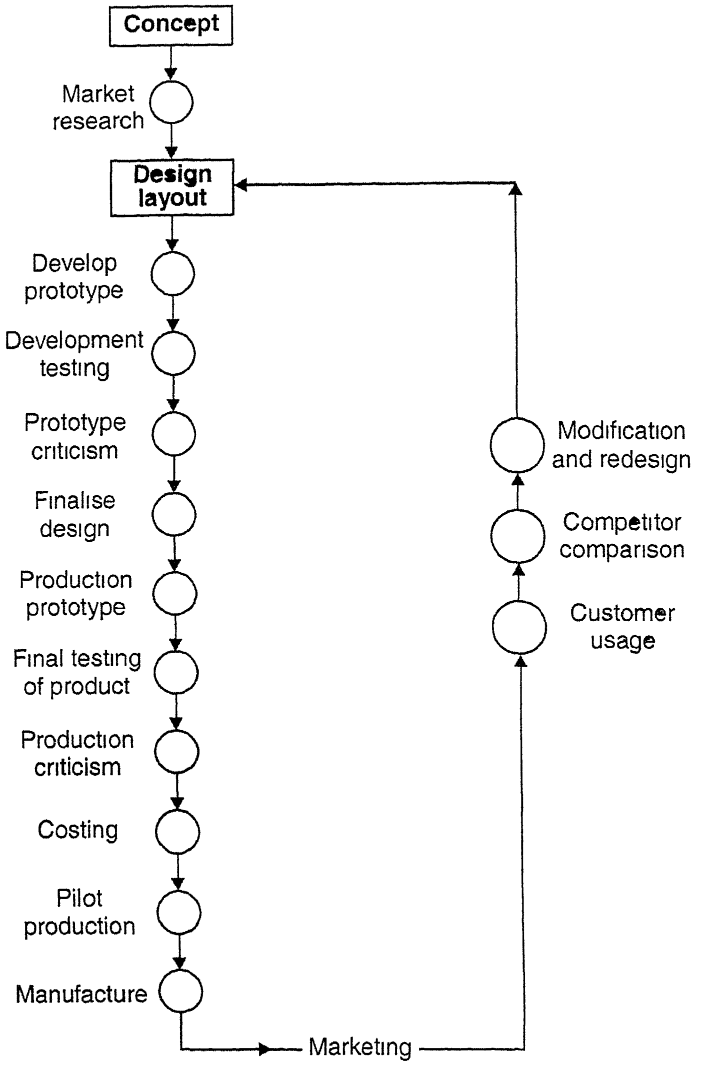


Fig. 3.7. Evolution process of a new product.

The following **requirements** *must be considered thoroughly at various stages of "evolution process" :*

(*i*) Cost of the product.
(*ii*) Quality and appearance of the product.
(*iii*) Market requirements.
(*iv*) Trend of competition.
(*v*) Trade requirements.
(*vi*) Materials and manufacturing techniques.

(*vii*) Quantity to be produced.
(*viii*) Function of the product

- The ultimate solution to the design problem must ensure that the product will be .
  — reliable;
  — economical to produce,
  — easy to maintain and satisfy the customer
- The development and production cost should be minimum and the time taken to design and produce the product should be least possible

Q. 3.6. Describe brainstorming method for evaluation of design concepts.

Ans. Brainstorming method for evaluation of design concepts is as follows .

(*i*) Select a group of around five persons to produce ideas.
(*ii*) State the problem as simply as possible.
(*iii*) Give ten minutes to each member to write down on a piece of paper as many ideas as occur to him.
(*iv*) Each member shall read one idea in turn and those listening, speak out to combine ideas.
— Criticism of any type is not permitted
— Humour is encouraged to relax the members and a cordial atmosphere is generated

- **Brainstorming** is *a black box method developed by Alex Osborne Blackbox methods do not focus upon the idea generation process and do not bother about the human brains processing capacity as a computer*

Q. 3.7. Distinguish between brainstorming and synectics.

Ans. Brainstorming and synectics are both idea generation by group but they have the following points of difference :

S. No.	***Brainstorming***	***Synectics***
1	The problem is defined clearly to the group A flood of ideas is collected, including ones which prime facie look silly.	The problem is *not stated* directly to the group However, the group is made aware of the actual problem during later stages of, say, a 3 hour session.
2.	Analogy is *not* used	Analogy is used such as symbolic, personal etc.
3.	The human brain is treated as a *black box* and the extent of stretching of imagination is limited.	Human brain is treated as a *glass box* and imagination is stretched to a maximum
4	The group comprises subject related individuals	A life scientist is present in the synectics group.
5	Criticism of all types is discouraged, wild ideas are produced.	Synectics generally leads group members towards the solution and wild ideas are not produced

Q. 3.8. Explain how a creative brainstorming session conducted. How this helps in problem solving and what are its drawbacks?

Ans. Brainstorming is a collectively idea generating approach that is used to find specific problems, causes of problems and solution to problems by accumulating ideas spontaneously contributed by a group of people.

'Brainstorming' *is a specific procedure that serves to foster creativity.*

• In a **brainstorming session** the participants may vary from 2-3 to 100 or more. The session is held in informal and comfortable atmosphere. Group is composed of both types of persons, experienced in the area of problem and persons with little experience. The leader begins by briefly reviewing the problem, leading to questions and answers session. On a piece of paper each person makes a list of his/her ideas. All the ideas so written are gathered and displayed. At the end all the ideas are reviewed and screened to limit to less number $\left(\text{about } \frac{1}{10}\text{th}\right)$ of ideas, depending upon the situation.

Drawbacks :

1. As it involves large number of people upto 100, coming to a decision sometimes is not possible.
2. Decision taken has to be tested before implementation.

No attempt is made to evaluate or analyse any of the ideas expressed during the session.

Q. 3.9. Explain in brief the different methods of gathering preliminary ideas for problem-solving and designing a new product.

Ans. The different methods/techniques of gathering preliminary ideas for problem-solving and designing a new product are discussed below :

(*a*) **Use of checklists :** This method forces the designer to use a checklist which acts as an aid for innovative designing. A lot of research into patterns of creativity is being done. Some of the points that can stimulate creativity are as under :

(*i*) Memories of past design.
(*ii*) Competitor's product.
(*iii*) Deliberate doodling and day-dreaming.
(*iv*) Self-questioning.
(*v*) Analogies.
(*vi*) Word-association.
(*vii*) Science fiction.
(*viii*) Deliberate distortion.
(*ix*) Initiating efforts to describe the process (Descriptive model).
(*x*) Definition of problem.
(*xi*) Use of formal proposals.

(*b*) **Techniques based upon forced creativity.** Second category of techniques based upon forced creativity are :

1. Brainstorming 2. Synectics.

1. **Brainstorming.** *Refer Q.3.6.*

2. **Synectics.** It is another method of collective problem solving A typical synectics group comprises about 5-6 persons from diverse areas. A group should have one and only one person having direct experience with the problem. A leader of the group himself does not contribute ideas but sees to it that any member does not dominate the proceeding. After the problem has been stated

clearly the *group members use analogies of various types* to understand the essential nature of the problem. Essentially, the following types of analogies are applied .

(*i*) Symbolic analogy.
(*ii*) Direct analogy.
(*iii*) Percent analogy.
(*iv*) Fantasy analogy.

Matrix approach or Morphological approach. *A matrix approach is applicable for single person idea generation instead of group effort* This approach *uses a matrix which makes it easier for less creative individuals to generate alternative design solutions*

This idea generation technique (single person based) includes the following ***steps*** .

(*i*) *Recognise the parameters essential to design* These can be functions that an acceptable design must perform or qualities which the design must have
(*ii*) *Determine the number of possible ways to achieve each parameter*
(*iii*) *Set up a matrix* with left hand column indicating parameter and top row indicating possible methods for achieving the parameter.
(*iv*) *Study all possible combinations for feasibility and decide upon the best*

Q. 3.10. What is 'Economic feasibility'? Explain.

Ans. After establishing that the product can be made, the materials and manufacturing methods to be used have been decided, and ensuring the performance of product as per requirements, the next step is to *work out the following* :

(*i*) The initial investment needed.
(*ii*) The addition expenses needed.
(*iii*) The means of financing
(*iv*) Income that will result.

In order to estimate economic feasibility, the prospective earnings must be compared with the prospective risks

Following are the *pertinent qualities to establish economic feasibility of a project* .

- Are there intangible benefits or risks that should be considered?
- Is the entrepreneur satisfied that the prospective return will warrant his financing the venture?
- In case loans to be taken, at what rate of interest and in how much time the loan and interest will be paid back. Are the additional risk of borrowing justifiable?

Q. 3.11. Enumerate fabrication requirements which should be considered at design stage.

Ans. Following *requirements may be considered at design stage* .

1. Material cost (including scrap cost).
2. Cost of dies, fixtures, moulds etc and their subsequent maintenance.
3. Type of machine tool to be employed
4. Ease of method of fabrication to be adopted
5 Cost influence by number of parts.
6. Cost and availability of machine shop equipment.

7. Minimum wall thickness required and possible.
8. Suitability for obtaining relatively thick walls
9. Possibility of obtaining walls of various thicknesses, bosses, and inserts in the same piece-part
10. Minimum core size possible and accuracy of core location.
11. Dimensional accuracy and uniformity of successive parts.
12. Long-time dimensional stability.
13. Cost of subsequent machining.
14. Smoothness of surface and cost of finishing.
15. Production speed.

Q. 3.12. What is "Morphological Analysis"?

Ans. The word **Morphology** *means the study of shape or form, so that "morphological analysis" is a way of creating new forms*

- **"Morphological analysis"** *is a systematic structured approach to problem definition and solution that use a simple matrix or morphological box.* This type of analysis works best when the problem can be readily decomposed into components or sub-problems. Each component should represent a meaningful and identifiable part of the major problem.

— The chief virtues of the *morphological box* is that it provides a *formal mechanism by which unusual or innovative problem solutions will not be overlooked in the thought process.*

Q. 3.13. What design guidelines should be followed during designing a system?

Ans. The following *guidelines* should be followed during *designing a system* :

1. Avoid arbitrary decisions.
2. Search for alternatives.
3. Use solid models.
4. Increase the level of abstraction at which the problem is formulated.
5. Make tables of design functions and options and use them to develop competing design concepts.
6. In developing source design concept always pursue it to the limits, and then back off. The limits will be set by physical realisability or economic constraints.
7. Aim for clarity of function.
8. Exploit materials and manufacturing methods to the fullest.
9. Develop a logical chain of reasoning for the design.
10. Ask questions (*i e.,* Is this part necessary?; What would happen if this component failed? etc.)

Q. 3.14. What essential steps are involved in the design process?

Ans. The following essential *steps* are involved in the design process :

1. To become acquainted with the design situation.
2. To prepare to deal with the design situation.
3. To identify the elements.
4. To analyse the elements.

5 To create the designs.
6. To evaluate the designs.
7. To rework the selected design.
8. To develop the selected design.
9. To prepare to communicate the design.
10. To gain acceptance of design.

Q. 3.15. What are the various methods of exploring design situations?

Ans. The different methods of exploring design situation along with their aim are as follows ·

1. Stating objectives.
2 Literature searching
3. Searching for visual inconsistencies
4 Interviewing users.
5 Questionnaires.
6. Investigating user's behaviour
7 Systematic testing.
8. Selecting scales of measurement
9. Data logging and data reduction.

Q. 3.16. Give comparison between 'Scientific method' and 'Design method'.

Ans. The comparison between 'Scientific method' and 'Design method' in given below ·

S. No.	*Scientific method*	*Design method*
1	Its origin is *curiosity*	It is the *need of society*
2	It starts with a *body of existing knowledge*	It starts with the *knowledge of the state of the art*
3	Formulated hypothesis is subjected to *logical analysis*.	Need is subjected to *feasibility analysis*
4.	*New idea* is generated.	An *acceptable product* is produced.
5.	It *enlarges* the body of the existing knowledge	It *advances* the state of the art of the particular field

Q. 3.17. Discuss briefly the reasons for adoption of probabilistic approaches in design.

Ans. Various reasons for adoption of probabilistic techniques are :

1. Theoretical validity of results.
2. Reliability.
3. Economic considerations.

It may be remembered that all phenomenon encountered in real world is multi-valued; inherently probabilistic; that reliability and failure probability have direct relationship; there is close correspondence between predicted and actual performance by considering variability of stress and strength; there is need of consistent reliability among the components of a system. Reliability goals can be incorporated and the levels of performance and safety can be determined.

Probabilistic design *results in improved design, requiring no testing, results in energy conservation due to adoption of minimum moving masses. It permits rational approach to costing and to establishing policy regarding replacements and warranties.*

Q. 3.18. What is the importance of 'Economics' in engineering design?

Ans. With the technological and financial support almost everything can be sold and produced. If a designer is not cost conscious, whatever good design he makes, it will be very difficult to implement it.

Economics in Engineering design is important due to many *reasons*, a few of them are as under :

1. It helps the designer to check the current performance with the planned program and then take suitable corrective actions, if necessary to improve the design.

2. It helps the designer to predict the cost of manufacture
3. It helps the designer to compare the cost estimate of various methods and to have a control on the cost of production.
4. It helps in reducing the human effort and in increasing wealth.

Q. 3.19. Explain briefly the various techniques used for optimising engineering problems.

Ans. The following techniques are used for optimising engineering problems :

1. Optimisation by evolution :

- This technique involves *improving existing designs or products by introducing different modifications.*
- Survival of a given alternative solution will depend on the natural selection of user acceptance.

2. Optimisation by intuition :

- This technique involves *making decisions without being able to formulate a justification.*
- Even with the present knowledge and analytical tools, intuition continues to play an important role in solving many engineering problems.

3. Optimisation by analytical methods :

- These methods deal with the *properties of maxima and minima and how to find maxima and minima numerically.*
- These methods can be grouped as :
  — Differential calculus;
  — Search methods;
  — Analytical graphical methods;
  — Linear programming;
  — Integer programming;
  — Dynamic (multistage) programming;
  — Geometric programming;
  — Non-linear programming;

Q. 3.20. Explain the concept of "Concurrent engineering".

Ans. Concurrent engineering (also called *simultaneous engineering*) *is a design approach in which product design and product manufacturing are merged in an intimate way.*

- The concurrent engineering concept really involves the model shown in Fig. 3.8, in which the people responsible for market analysis are intimately involved as are those concerned with distribution and sales. An important aspect is to incorporate the idea of designing for a lifetime to use, *i.e., life cycle engineering.*
- The *primary objective of concurrent engineering is to move engineering changes back into the early stages of design.*
- The benefits of concurrent engineering extend well beyond achieving radical manufacturing cost.

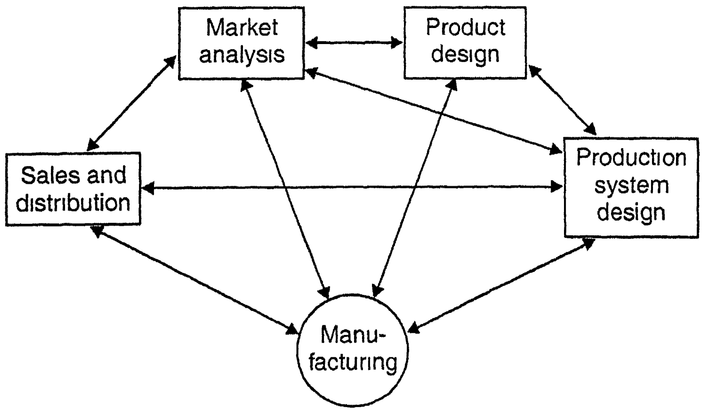


Fig. 3.8. Model of concurrent engineering.

Q. 3.21. What is the importance of decision making?

Ans. The importance of decision making is felt due to the following *reasons* .

1. To achieve the goals of business decisions are required.
2. A plan cannot be said to exist unless a decision, a commitment of resources, direction etc. has been made.
3. Each aspect of management functions such as planning, organising and control is determined by decisions.
4. There is increased pressure on performance because of increased production Therefore, slight variation in any of the operating parameters may have tremendous impact on the performance of the production system and hence it needs speedy decision.
5. Decision is required to keep the business wheel move.

Q. 3.22. Explain briefly the various techniques adopted for decision making according to the problem definition.

Ans. The various techniques adopted for decision making are :

1. **Operational research technique.** It comprises of *probability theory, linear programming, inventory theory* etc.
2. **Mathematical analysis.** It involves the application of *established mathematical theories or relationships.*
3. **Models.** The models serve power tool or technique making decisions. In this technique a model of product is formed and then tested or judged by various methods.
4. **Computer simulation.** It is the technique which involves the process of building, testing and operating models of real world phenomena through the application of mathematical theories or relationship that exist among critical factors.

Q. 3.23. What do you understand by "Critical decision making in design"?

Ans.

- *A critical decision is final and once chosen, the management is committed to it.* Design can proceed from preliminary stage to final state of physical realisation; only in extra-ordinary circumstances can the selected concept be changed, when penalty of such a virtual failure is very high.

- Critical decision rests on comparison of advantages and difficulties associated with each of the possible solutions. The advantages are evaluated on some utility scale, and difficulties emerge as sub-problems, which must be resolved if the given concept of solution is to be capable of physical realisation.
- Design work has to proceed within allotted budget (of time and money) at each major phase.
- Critical decisions take account of the severity of the penalty resulting from the failure of a chosen concept. Critical decision is taken by a person who can take the responsibility for failure of a design concept.

Q. 3.24. For any selected project, what all questioning is necessary to perform need analysis and validation for the selected project?

Ans. The following questioning should be satisfactorily answered for needs analysis and validation for the selected project :

1. What is primitive or simplest statement of need?
2. What are special needs of the consumer, the distributor, the manufacturer?
3. Is there is any real conflict among any of these needs, which must be stated as clearly as possible?
4. Projection about future needs.
5. Initial statement of the broad goal.
6. Establish the criteria of success (like income from sales will be sufficient to meet all operating costs, pay off the initial plant investment, and earn a profit sufficient to warrant the risk in starting the project etc.). All the criteria of success should be listed in order to importance.

Q. 3.25. What are the possible aids for innovative thinking?

Ans. Following can be the various *aids for innovative thinking* :

1. Review historic information.
2. Develop *backlog of ideas* (build own storehouse of information through curiosity and observation).
3. Break mental set by imagining a completely new set of fundamental conditions.
4. Brainstorming.
5. Use analogy (direct, personal and symbolic).
6. Analyse morphologically.

Q. 3.26. Discuss the importance of estimation. Why is it important and how it is developed?

Ans.
- It is important that a designer should be able to make quick and accurate estimates of various situations. Even in complex situations, simple equivalents can be estimated as preliminary information guides or as checks on the other computations.
- Estimates can be made by imaginary measurements, rough calculations from simple equivalents (applying a physical law to a simplified form of the situation), graphics, and intuition (from memory and only partly reasoned).
- Evaluation is very much required to *check the viability of the project.*

Q. 3.27. What are the blocks/resistances to the creative approaches in designing?

Ans. The following are some of *blocks of the creative approaches in designing* :

1. Fear for failure.

2. Fear for criticism.
3. Fear for spending money on new methods.
4 Fear of making mistake.
5. Unwillingness to change the conventional method.
6. Inability to collect information.

Q. 3.28. What are "Expert systems"? Explain briefly.

Ans.

- **"Expert systems"** called (*knowledge-based systems*) comprise one of the forefront areas of the exciting field of *artificial intelligence* (*AI*). Other areas of artificial intelligence are :
  — Automated reasoning; — Machine learning;
  — Intelligent databases; — Natural languages;
  — Knowledge acquisition; — Vision and sensing.
  — Knowledge bases and knowledge representation;
- An expert system acquires knowledge through knowledge-acquisition software tools from a trained specialist called a *knowledge engineer* (who obtains knowledge from domain experts).
- The main ***advantage*** *of expert systems* is that they capture the knowledge of experts that may otherwise be lost through death or retirement. However, it be added that expert systems are *not* a substitute for a human expert. Unless a problem is fully understood, which can come only from humans, the expert system project will fail.
- Expert systems find **applications** in the following fields :
  (*i*) In *"industry"* for such tasks as :
  — Analysis of quality control data,
  — Assisting manufacturing personnel to safely operate machinery, and
  — Accurately time instruments.
  (*ii*) A common application relates to the troubleshooting of equipment that breaks down or the readjustment of equipment that drifts out of calibration.

Q. 3.29. List the benefits of "Expert systems".

Ans. Some of the benefits expected from "*Expert systems*" are :

1. The ability to reduce the cost of design while at the same time improving quality.
2. The ability to eliminate errors in problem solving.
3. The ability to capture valuable expertise and then to put it comfortably into the hands of a novice.
4. The ability to search large databases for optimal selection of concepts, components and materials.
5. The ability to interface the expert system with advanced software for engineering analysis. By further increasing the analytical capacity, the amount of detail the system can cope with is expanded.
6. The ability to search design libraries for similar designs, so that engineers can learn from past experience and avoid duplication.
7. The ability to improve the consistency of design within an organisation.

Q. 3.30. What are the aims of information system?

Ans. The *aims of information system* are as under

1. To provide effective communication with the user.
2. To act as a reliable and logical data supply.
3. To bring the new facts to the knowledge.
4. To give the essential information and feedback for a problem.

HIGHLIGHTS

1. *Design concept* signifies the validity of the design idea.
2. *Concept selection* is the process of evaluating concepts with respect to customer needs and other criteria comparing the relative strengths and weakness of the concepts and selecting one or more concepts for further investigation, testing, or final development.
3. The following types of tests are usually used to qualify design concepts :
   (*i*) Scale model tests
   (*ii*) Development tests
   (*iii*) Prototype tests
   (*iv*) Proof tests
   (*v*) Acceptance tests
   (*vi*) Model tests.
4. Unresolved needs are called *problems*. The following *steps are involved in solving a problem* ·
   (*i*) Design process
   (*ii*) Thought process
   (*iii*) Professional method
   (*iv*) Problem solving
   (*v*) Scientific method
   (*vi*) Other approaches.
5. The *morphology* of design engineering deals in structural engineering based on realistic assessment and field requirements.
6. Morphology of design refers to the following *phases* :
   (*i*) Feasibility study
   (*ii*) Preliminary design
   (*iii*) Detail design
   (*iv*) Planning to manufacture
   (*v*) Planning for distribution
   (*vi*) Planning for use.
7. *Brainstorming* is an idea generating approach that is used to find problems, causes of problems, causes of variation, ways to prevent problems, solution to problems, or ways to implement these solutions.
8. A *decision* is the conclusion of a process by which one chooses between two or more available alternative courses of action for the purpose of attaining goal; the process is called *decision making*.
9. The *physical realisability* of alternative solution depends on an inter-relationship between several factors.
10. *Morphological analysis* recognizes that the solution to a design problem consists of certain essential constituent parts and a good design is one which selects the proper '*matching*' combination of components.
11. Value Engineering (VE) is normally used in relation to design of new products and 'Value Analysis' is normally used in relation to existing products.

OBJECTIVE TYPE QUESTIONS

Fill in the Blanks or say 'Yes' or 'No' :

1. . .... concept signifies the validity of the design idea.
2. Proof tests provide less important data for verification of design.
3. Verification of design is mainly dependent on proof test.
4. . .. . test is carried out on the final production product to verify that the product meets the design requirements.
5. ... . in engineering design deals with information in engineering design.
6. The .... of design engineering deals in structural designing based on realistic assessment and field requirements.
7. The attitude of the designer changes from phase to phase.
8. . . . . is an idea generating approach that is used to find problems, causes of problems, causes of variation, ways to prevent problems, solution to problems, or ways to implement these solutions.
9. A .. . . represents a course of behaviour chosen from a number of possible alternatives.
10. A critical decision is final and once chosen, the management is committed to it.

ANSWERS

1. Design	**2.** No	**3.** Yes	**4.** Acceptance	**5.** Infonomics
6. morphology	**7.** Yes	**8.** Behaviour	**9.** decision	**10.** Yes.

THEORETICAL QUESTIONS

1. Define the term 'Design concept'.
2. Enumerate the steps involved in the 'concept operation methodology'.
3. What is 'concept selection'? Explain.
4. Explain briefly the following stages of 'concept selection':
   (*i*) Concept screening.
   (*ii*) Concept scoring.
5. Explain briefly the various types of tests which are commonly used to qualify design concepts.
6. What do you understand by the term 'Infonomics'?
7. Explain briefly the various inputs for engineering design information system.
8. How is 'Information' classified?
9. Enumerate the various sources of information
10. List the various methods of obtaining information.
11. What problems are encountered in collecting information?
12. What points should be considered in reporting a design?
13. Enumerate and explain the steps involved in solving a problem.
14. What do you understand by 'Morphology of design'? Explain.
15. Explain with a neat figure the repeated graphic module used in various stages of morphology of design.

16. Explain briefly the various phases of "Morphology of design"
17. What is 'Brainstorming'? Explain.
18. Explain briefly the following phases of brainstorming .
(*i*) Idea-generation phase.
(*ii*) Idea-evaluation phase.
19. List the rules for 'creative techniques'.
20. Explain briefly the following creative techniques :
(*i*) Osborn's brainstorming technique.
(*ii*) Phillips buzz session technique.
(*iii*) Crawford slip writing technique.
21. Define the terms 'Decision' and 'Decision making'
22. Explain briefly the following types of managerial decisions :
(*i*) Programmed and non-programmed decisions.
(*ii*) Major and minor decisions.
(*iii*) Routine and strategic decisions.
(*iv*) Organisational and personal decisions.
(*v*) Individual and group decisions.
(*vi*) Policy and operative decisions
(*vii*) Long-term, developmental and non-economic decisions.
23. Discuss briefly the following theories of decision making :
(*i*) Marginal theory.
(*ii*) Mathematical theory.
(*iii*) Psychological theory.
24. List the steps comprising scientific approach.
25. Explain with a neat figure the relationship of scientific approach to the decision making process.
26. List the guidelines which may be followed for effective decision making.
27. What is 'Physical realisability'. Explain.
28. Explain the process of resolving physical realisability.
29. Enumerate some important new methods of design.
30. Describe briefly the various stages which are involved in any design product.
31. What is 'Morphological analysis'? Explain.
32. List the positive steps which enhance 'creating thinking'.
33. Discuss briefly 'Creative design routes'.
34. What are the characteristics of good design?
35. What steps are involved in designing a product?
36. List the steps which are associated with design process.
37. What is 'Probabilistic design'? Explain.
38. Explain briefly the following :
(*i*) Value Analysis.
(*ii*) Value Engineering.

4

Detailed Design

4.1 Introduction, 4.2. General considerations in machine design, 4.3. Manufacturing considerations in design, 4.4 Points to considered while designing for 'Casting', 'Forging', 'Easier machining', 'Heat treatment', 'Welding', 'Steel casting' and 'Die casting' 4.5. Ideal characteristics of a part of an assembly, 4.6. Designing for manufacturing, 4.7. Maintainability criteria — General aspects — approaches for improving the maintainability of design — maintainability of an equipment — How to ensure high maintainability — maintainability during design stage — maintenance of plant — types of maintenance — effective maintainability in design, 4.8. Aesthetics — General aspects — concepts of aesthetics in engineering — aesthetic elements for engineering design, 4.9 Design specifications and drawings, 4.10. Designing for function, 4.11. Designing for production, 4.12. Designing for shipping, handling and installing, 4.13. Visual design. **Questions with Answers** *— Highlights — Objective Type Questions — Theoretical Questions.*

4.1. INTRODUCTION

Detailed design *is a phase of morphology and is concerned with arriving at final drawing of any product. It may be an assembly, sub-assembly components and parts of the product.*

A concept generation or an idea have limited use until it comes into final working drawing or the model of the product which is also known as the *prototype*. After the finalisation of the prototype of any product, the design proposal made by the design team is accepted.

The *detailed phase of any product consists of the following* **steps :**

1. Design calculation.
2. Determination of critical dimensions of parts.
3. Components.
4. Sub-assembly and final assembly.
5. Necessary tolerances, clearances, surface finish and accuracy requirements are stated and the final step of the detail design is the preparation of assembly drawing.
6. Constructing experimental full-scale prototype of the product.
7. Product test programme.
8. Redesign if required.

4.2. GENERAL CONSIDERATIONS IN MACHINE DESIGN

General considerations in designing a machine component are :

1. Type of load and stresses caused by the load.

2. Motion of the parts or kinematics of the machine.
3. Selection of materials.
4. Form and size of the parts.
5. Frictional resistance and lubrication.
6. Convenient and economical features.
7. Use of standard parts.
8. Safety of operation.
9. Workshop facilities.
10. Number of machines to be manufactured.
11. Cost of construction.
12. Assembling.

4.3. MANUFACTURING CONSIDERATIONS IN DESIGN

For a design engineer, the knowledge of manufacturing processes is of great importance. Following manufacturing processes are generally used :

1. Primary shaping processes. Primary shaping processes are those processes which are used for the *preliminary shaping* of the machine components. The common operations used for these processes are :

— Casting
— Forging
— Extruding
— Rolling
— Drawing
— Bending
— Shearing
— Spinning
— Powder metal forming
— Squeezing etc.

2. Machining processes. These processes are used for giving *final shape* to the machine component, according to the planned dimensions. The common operations used for these processes are :

— Turning
— Planing
— Shaping
— Drilling
— Boring
— Reaming
— Sawing
— Broaching
— Milling
— Grinding etc.

3. Surface finishing processes. These processes are used to provide a *good surface finish* for the machine components. The common operations used for these processes are :

— Polishing
— Buffing
— Honing
— Lopping
— Abrasive belt grinding
— Barrel tumbling
— Electroplating
— Superfinishing etc.

4. Joining processes. These processes are used for *joining machine components.* The common operations used for these processes are :

— Welding
— Riveting
— Soldering
— Brazing
— Screw fastening
— Pressing etc.

5. Processes effecting changes in properties. These processes are used to *impart certain specific properties* to the machine components so as to make them suitable for particular operations or uses Such processes are :

— Heat treatment — Hot working
— Cold-working — Shot peening etc.

4.4. POINTS TO BE CONSIDERED WHILE DESIGNING FOR 'CASTING', 'FORGING', 'EASIER MACHINING', 'HEAT TREATMENT', 'WELDING', 'STEEL CASTING' AND 'DIE CASTING'

The various points to be considered while designing 'casting', 'forging', 'part for easier machining', 'heat treatment', 'welding', 'steel casting' and 'die casting' are as follows ·

1. CASTING. For designing a good casting the following factors need be considered :

- Function to be performed by the casting.
- Soundness of the casting.
- Strength of the casting.
- Ease in production of the casting.
- Consideration for safety.
- Economy in production

For meeting the above mentioned requirements, a designer should have a thorough knowledge of the *production methods* including *pattern making, moulding, core making, melting* and *pouring* etc.

Rules for designing castings. A *few rules* for designing castings are given below to *serve as a guide* ·

(*i*) The casting should be designed as *simple as possible*, but with good appearance.
(*ii*) In designing a casting, the various *allowances must be provided* in making patterns.
(*iii*) In order to avoid concentration of stresses, the *sharp corners* and *frequent use of fillers should be avoided*
(*iv*) *Large flat surfaces* on the casting should be *avoided,* because it is difficult to obtain true surfaces on large castings.
(*v*) All sections in a casting should be designed of *uniform thickness*, as far as possible. If, however, variation is unavoidable, it should be done gradually.
(*vi*) The casting should be designed in such a way that it will *require a simpler pattern* and its moulding is easier.
(*vii*) An *abrupt change* of an extremely thick section into a very thin section should always be *avoided.*
(*viii*) The *use of metal inserts* in the casting should be kept *minimum.*
(*ix*) The *markings* such as names or numbers etc should *never be provided* on vertical surfaces because they provide hindrance in the withdrawal of the pattern.
(*x*) The *stiffening members* such as webs and ribs used on a casting should be *minimum* possible in number, as they may give rise to various defects like hot tears and shrinkage etc.

(*xii*) The deep and narrow pockets in the casting should be invariably avoided, to *reduce cleaning costs.*

(*xiii*) The ability to withstand contraction stresses of some members of the casting may be improved by providing the *curved shape*, *e.g.*, the arms of pulleys and wheels.

2. Forging. While designing a 'forging', the following points should be considered :

(*i*) The *sharp corners* should always be *avoided* in order to prevent concentration of stress and to facilitate ease in forging

(*ii*) The *ribs should not be high and thin.*

(*iii*) The forged components should ultimately be able to achieve a *radial flow of grains or fibres.*

(*iv*) *Too thin sections should be avoided to* facilitate easy flow of metal.

(*v*) The *pockets and recesses* in forgings should be *minimum,* in order to avoid increased die wear

(*vi*) The *parting line of a forging* should lie, as far as possible, in *one phase*

(*viii*) The forgings which are likely to carry flash, such as drop and press forgings, should preferably have the parting line is such a way that the same will *divide them in two equal halves.*

3. Easier machining :

(*i*) For economy or low cost manufacture, the design should be such as *to involve minimum machining and reducing the area of machined surfaces.*

(*ii*) *Adequate gripping surface* should be provided on parts for machining purposes.

(*iii*) *Provide flat surfaces for drilling,* in order that drill, while cutting, always meets equal resistance on its cutting edges.

(*iv*) The part designed can be *machined with existing tooling equipment*

(*v*) *Ribs* should not be allowed to *interfere with machining.*

(*vi*) *Double fits should be avoided* as single fits allow tighter tolerances.

(*vii*) Drilling of *sloping surfaces* should be *avoided.*

(*viii*) The holes should be so positioned that they are accessible to the drill and holes should never be placed *too near the edge of the work.*

(*ix*) For better clamping, the different surfaces must be designed to be kept on the *same plane.*

(*xi*) The *external threads* should be provided on the *longer rods.*

(*xii*) When the flanges are not of circular form, *dowel pins*, spaced as far apart as possible, to ensure positive location of the flanges, *should be provided.*

(*xiii*) *Suitable tenons and locating faces* should be provided to prevent cracking and warping in heat treated parts.

(*xiv*) A *centering spigot* should be provided to obtain easy coaxial assembly for the turned components intended to be bolted up together.

4. Heat treatment :

(*i*) Have *uniform thickness* and avoid sudden change to section to ensure balanced heating and cooling.

(*ii*) Avoid *junctions* of holes in steel block.

(*iii*) *Abrupt changes* of workpiece contours should be *avoided* to prevent cracking and warping in heat treated parts

(*iv*) *Avoid blind holes*

(*v*) As far as possible, the part should be shaped such that every point of any section or surface on it receives and gives back the *same amount of heat* with the *same speed.*

5. Welding :

(*i*) A weld should not be located at the *point of maximum deformation.*

(*ii*) Large flat walls, which *tend to buldge* and flex should be *avoided.*

(*iii*) *Avoid machining near weld area*

(*iv*) Welds should be located so that *adequate strength* will be provided at the proper places on a structure or part

(*v*) *Sharp discontinuities* in metal should be *avoided* to reduce stress concentrations

(*vi*) Provide for *easy access to welds*, so that they are accessible for inspection

(*vii*) As far as possible, a *straight line force pattern* should be provided, laps, straps and stiffening angles should be provided; the ends to be welded be of equal thickness, properly prepared grooves should be used.

(*viii*) *Heavy loading* over long welds should be distributed in the *longitudinal direction.*

(*ix*) Welds at vulnerable cross-sections should be *avoided,* and welds should *not* be subjected to *bending*

(*x*) Thermal contraction of metal (heated by welding) may cause residual stresses and distortion. These can be controlled by *preheating, minimum number of welds, smallest size of weld that fulfills requirements* and *maximum use of intermittent welds*

6. Steel casting. Steel not being as fluid as cast iron, complicated shapes, *sharp corners and thin sections cannot be cast* The *minimum thickness of steel castings is usually taken as 6mm* (In small castings minimum thickness can be 4.5 mm).

- All steel castings *must be annealed to relieve internal stresses*
- The *contraction* of steel as compared to cast-iron is *double* Thus the designer must aim to secure *maximum uniformity in contraction.* This can be achieved by using *uniform wall-thickness, avoiding concentration of metal* etc
  — The tensile strength of steel being about four times greater than that of cast-iron, and its tensile and compressive strengths being nearly equal, designer has more freedom in choosing the shapes for steel casting
- *Steel castings have smaller dimensions and are lighter in weight* Steel castings will be better suited for structures requiring *stiffness.*
- By *suitable form design, steel castings can acquire fatigue resistance.*

7. Die casting :

(*i*) Due to *high sensitivity* of light alloys to stress concentration, large *fillets should be provided.*

(*ii*) Notches should be avoided.

(*iii*) The *wall thickness should be kept as uniform as possible.* The minimum thickness for brass and bronze is 2.3 mm and for aluminium it is 3 mm.
(*iv*) Allow draft where necessary.
(*v*) Avoid partly closed shapes and closed cavities.
(*vi*) Provide for easy flash removal.
(*vii*) Provide shrinkage and machining allowances.

4.5. IDEAL CHARACTERISTICS OF A PART OF AN ASSEMBLY

The two products having an identical number of parts may nevertheless differ in required assembly time by a factor of two or three. This is owing to the fact that *the actual time to grasp, orient and insert a part depends on the part geometry and the required trajectory of the part insertion.*

Follows are the *ideal characteristics* of a part of an assembly :

1. *Part is inserted from the top of the assembly :*
   - This attribute of a part and assembly is called Z-axis assembly. By using Z-axis assembly for all parts ;
     — The assembly never has to be inverted;
     — Gravity helps to stabilize the partial assembly;
     — The assembly worker can generally see the assembly location.
2. *Part requires only one hand assembly :*
   - All other things being equal, parts requiring one hand to assemble require less time than parts requiring two hands, which in term require more parts requiring a crane or lift to assemble.
3. *Part requires no tools :*
   - Assembly operations requiring tools (such as attaching snap rings, springs, or cotter pins) generally require more time than those that do not.
4. *Part is assembled in a single, linear motion.*
5. *Part is self aligning :*
   - The most common self-aligning feature is the chamfer. A chamfer can be implemented as a tapered lead on the end of a peg, or a conical widening at the opening of a hole.
6. *Part does not need to be oriented :*
   - The parts requiring correct orientation, such as a screw, require more assembly time than parts requiring no orientation, such as a sphere.

4.6. DESIGNING FOR MANUFACTURING

The term **Design for manufacturing** *(DFM) may be defined as establishing the shape of components to allow for efficient, high quality manufacture.*

The key concern of DFM is in specifying the best manufacturing process for component and ensuring that the *component form supports the manufacturing process selected.* For any component there are several manufacturing processes that can be used in its manufacture. For

each manufacturing process there are design guidelines, if followed, would *result in consistent components and little waste :*

The design of the tooling and fixturing should be treated concurrently with the development of the component. In the days of overall product design processes, design engineering would sometimes release drawings to manufacturing for components that might be difficult or impossible to make. The *concurrent engineering philosophy,* with manufacturing engineers as members of the design team, helps avoid these problems.

Design For Assembly (DFA) *is the best practice used to measure the ease with which a product can be assembled.*

- The *"ease of assembly" is directly proportional to the number of components that must be retrieved, handled and mated, and the ease with which they can be moved from their storage to their final, assembled position.*
  — Each act of retrieving, handling and mating a component or repositioning an assembly is called as *assembly operation.*
  — Component handling is a major consideration in the measure of assembly quality Handling encompasses safe and skilful handling of the retrieved component into position, so that it is oriented for assembly.
- *"Component mating" is the act of bringing components together.* Mating may be minimal, like setting one component on the flat surface of another or it may require threading a fastener into a threaded hole. A term offen synonymous with mating is *insertion.* During assembly some components are inserted in holes, others are placed on surfaces, and yet others are fitted over pins or shafts.
- **DFA** *measures a product in terms of the efficiency of its overall assembly and the ease with which the components can be retrieved, handled and mated*

4.7. MAINTAINABILITY CRITERIA

4.7.1. General Aspects

Maintainability may be *defiend* as follows :

"It is the probability that a device can be restored to operational effectiveness within given period when maintenance action is performed on it in accordance with prescribed procedures".

Or

"The combined qualitative and quantitative characteristics of equipment design which enable the accomplishment of maintenance resources, including manpower, personal skill, test equipment, tools and aids, technical documentation and spare parts under operational environments in which scheduled and unscheduled maintenance is performed".

The **object of maintainability** *is to design and develop systems and equipment which can be maintained in the least time, at the least cost, with a minimum expenditure of engineering support resources, without adversely affecting the item performance or safety characteristics.*

— The maintainability can be predicted based on an analysis of the design.

- The *main criteria of maintainability of an equipment* is that :
  — it must have high availability;

— mean time to repair the fault should be minimum;
— it should be possible to increase mean time between failures by undertaking preventive maintenance at regular intervals.

- The ease of fault detection, isolation and repair are all influenced by system design and are main factors contributing to maintainability. The timely supply of spare parts, the supporting repair organisation and the preventive maintenance practice, also contribute to maintainability.
- *Good maintainability may somewhat offset low reliability.* Thus if the desired reliability cannot be met because of performance constraints, improvements in system maintainability can help overcome the problem.
- **"Serviceability"** *affects maintainability.* It is defined as the degree of ease with which a system can be repaired. It specifically considers the *fault detection, isolation* and *repair.*
- **Availability** is *the function of both reliability and maintainability.*
- **Troublefree dependability** is the property enabling a machine to retain its working capacity during a given operating time without mechanical stoppage.
- **Durability** is the property of a machine to retain its working capacity upto its limiting stage with the necessary stoppage for repair and servicing. It is a special case of reliability. It is defined *as the probability that an item will fully survive its projected life, or rebuild point without a durability failure.*

4.7.2. Approaches for Improving the Maintainability of Design

The approaches for improving the specific maintainability of design may be both *general* and specific. These are discussed below :

General approaches include the following :

(*i*) Reliability versus maintainability.
(*ii*) Modular versus non-modular construction.
(*iii*) Repair versus throwaway.
(*iv*) Built-in versus external test equipment.
(*v*) Person versus machine.

Specific approaches are *based on detailed checklist that are used as a guide to good design for maintainability.*

Maintainability can also be demonstrated by *test.* The demonstration consists of measuring the time needed to locate and repair malfunctions or to perform selected maintenance tasks.

4.7.3. Maintainability of an Equipment

The following factors contribute to maintainability of an equipment :

1. Assessibility of assemblies and components.
2. Standardisation.
3. Procedures.
4. Monitoring facilities.

5. Identification.
6. Safety.
7. Training.
8. Availability of literature.

Although maintainability is improved by above factors at the design stage, the equipment availability will improve only by proper interaction amongst the various agencies involved in the equipment management during the in-service phase.

4.7.4. How to ensure High Maintainability?

The following points should be considered by a designer *to ensure high maintainability :*

1. Use standardize parts.
2. Use modular or unit packaging.
3. Use self lubricating principles.
4. Use sealed and lubricated components.
5. Employ self-adjusting mechanisms.
6. Provide built-in testing and calibration feature.
7. Use gea-driven accessories in preference to belt and pulleys.
8. Simplify operator and maintenance functions and use simple design.
9. Design for :
   - Maximum safety and protection of personnel;
   - Quick and positive recognition of marginal performance/malfunction;
   - Quick position recognition of the replaceable defective components;
   - Optimum accessibility of all components/system/equipment.

4.7.5. Maintainability during Design Stage

"Maintainability" is a part of design process. Maintainability analysis is carried out at *"preliminary stage"* and *"detailed"* design stage :

- *Analysis required during "Preliminary stage"* include the following :
  (*i*) Maintainability requirements.
  (*ii*) Maintenance concept.
  (*iii*) Maintainability feasibility estimation.
  (*iv*) Maintainability allocation.
- *Activities performed during "Detailed design"* are :
  (*i*) Maintainability predictions;
  (*ii*) Preparation of guidelines and checklists to prevent recurrence of frequently observed maintenance problems;
  (*iii*) Design trade off studies;
  (*iv*) Other maintainability analysis such as :
  — Address diagnostic requirements;
  — Diagnostic effectiveness level;
  — Location of repair;

— Ease of maintenance;
— Maintenance task analysis;
— Skill analysis etc.

4.7.6. Maintenance of Plant

It is very essential to have *uninterrupted operation* of manufacturing process for keeping down production cost at a minimum and orders which have been made to, should be delivered promptly.

"Maintenance" contributes to the reliability and durability of machine.

The maintenance department usually performs the following *functions* :

1. To make emergency repairs.
2. To make routine repairs that are not of an emergency nature.
3. To keep the building and ground in clean sanitary conditions.
4. To inspect the buildings, equipment and machines to find out misused or needed repairs.
5 To equip machines up–to–date so as to make maximum use of the available manpower and to minimise the disturbance of operations.
6. To keep up records of the various machines and equipment as a guide to the proper use and selection of the new equipment for a given purpose.
7. To maintain the cost records for machines for use to the management.

4.7.7. Types of Maintenance

Maintenance may be of the following *types* :

1. Routine or periodical maintenance.
2. Breakdown maintenance.
3. Preventive maintenance.

1. Routine or periodical maintenance. The routine or periodical maintenance include the following :

— Inspection;
— Lubrication;
— Periodical replacement of spare parts;
— Upkeep of buildings and grounds and protection.

Cleaning and lubrication of machines will have smooth running; the workers will feel it easy to operate the machines.

2. Breakdown maintenance. Sometimes the production machine undergoes breakdown suddenly without prior warning. Priority will be given to emergency breakdown in order to minimise interruption of the firm's current productive operation. In all such cases, the causes of the breakdown should be noted and steps are to be taken to see that similar breakdowns do not occur in future.

3. Preventive maintenance. The *preventive maintenance is more efficient than remedial maintenance.* The machines and equipments should be *inspected periodically* to avoid risks and losses which are arising from not making repair before damages had occured. Preventive inspection should be scheduled according to the need of given situation.

4.7.8. Effective Maintainability in Design

In order to provide effective maintainability, the following factors must be considered early in the design and must be continually refined as the design progress :

1. Repair policies.
2. Analysis and prediction of maintainability.
3. Design factors affecting maintainability.
4. Human factors affecting maintainability.

1. Repair policies. Repair policies may be adopted which require the design of any of the following :

- Fully repairable systems.
- Partially repairable systems.
- Non-repairable systems.

2. Analysis and prediction of maintainability. In this analysis the following activities are involved :

— To describe maintainability tasks;
— To select repair policy;
— To establish repair time for components, subsystems and systems.
— To develop equipment test procedures;
— To develop repair procedures;
— To develop calibration and adjustment procedures;
— To develop methods for localising malfunctions;
— To establish test equipment and repair tool requirements;
— To establish technical manual requirements;
— To establish spare parts requirements;
— To identify number and types of maintenance personnel and their training requirements.

- *This analysis can be performed by breaking down the trouble-shooting procedure into the various logical steps which would be taken based on the symptoms of the malfunction.*

3. Design factors affecting maintainability. Design factors affect the maintainability considerably. Following are some of the factors which can be provided in the design of equipment to improve maintainability :

— To provide convenient access;
— To use removable plug-in units;
— To use standard and interchangeable parts;
— To use marginal checking;
— To provide simple test procedure etc.

In order to determine which factor should be employed, it is necessary to estimate the contribution to the *reduction in repair time and effect on system cost for each factor, and to compare these values for the several factors.*

4. Human factors affecting maintainability. In connection with maintenance, there are following three categories of human factors and considerations :

(*i*) *Capabilities and limitations of personnel :*

— One approach to organising personnel for maintenance is to use the least capable personnel at user installations in conjunction with a no repair or minimum repair policy at the user level and to place higher skill personnel in central maintenance facilities.

(*ii*) *Equipment design :*

— It is possible to reduce downtime by providing free access for the inspection service, repair, or replacement of equipment. The least reliable units should be the most accessible.

— The limited amount of scheduled maintenance may be performed without halting equipment operation.

(*iii*) *Environmental design.* In system design, the following maintenance environmental conditions should considered :

- Ambient air conditions (*e.g.*, temperature, relative humidity, air circulation, purity).
- Illumination.
- Noise.
- Vibration.

4.8. AESTHETICS

4.8.1. General Aspects

It is true that the prime design consideration for any product must be that it will function correctly and be constructed sound enough to go on functioning for the extent of its planned service-life, but a good designer must lay equal analysis on *form, arrangement, appearance and other aspects of the aesthetic quality of the object.*

- Aesthetic quality in engineering design can be achieved in the following two ways:
  (*i*) Through *elegance of concept ;*
  (*ii*) Through *elegance of realisation.*

4.8.2. Concepts of Aesthetics for Engineering

For any engineerng design, *aesthetics is a critical part.* Various concepts of aesthetics for engineering are :

1. Function 2. Form
3. Unity (harmony) 4. Styling.

1. Function :

- It is important for the customer to recognise by means of the aesthetic treatment what the product is intended to do and how it is to be used.
- In the development of a design, function is not limited to the purely mechanical operation of an object, but cost, environment, user acceptance and familiarity, maintenance, and service, as well as aesthetics are the responsibility of a designer.

2. Form :

- The form involves the overall visual appearance of an object. It consists of elements like line, proportion, colour and texture.
- A good form clearly identifies itself and its function.

3. Unity (harmony) :

- Unity in a product means that it appears to be complete. A proportional relationship exists between all parts contributing to an orderly whole.
- Too much variety results in the destruction of unity, because the relationship of the visual elements is lost. A designer must be able to recognise and create the delicate balance of unity with variety within the framework of an object's form.

4. Styling :

- It refers to decoration and ornamentation. It is used to promote the sale of goods.
- It is different from aesthetic quality which results from proper function, form and unity. *Example.* The outward appearance of an automobile to generate consumer's interest.
- *Styling relies primarily on the emotional qualities of aesthetics.*

4.8.3. Aesthetic Elements for Engineering Design

Following are the *basic elements* which are used to *create an aesthetically satisfying design :*

1. *Lines* — It is a symbol that defines where one form ends and another begins.
2. *Mass* — It imparts a sense of weight or heaviness or solidity to an object.
3. *Space* — The figure of objects attracts and holds one's attention.
4. *Balance* — It is a manifestation of equilibrium and its existence provides observer with a sense of comfort and security.
5. *Proportion* — Proportions are effective elements for achieving aesthetical balance and the concept of unity.
6. *Contrast* — It improves the legibility and is useful for drawing attention to or emphasizing a component with a design.
7. *Colour.* Colours have an emotional quality, a psychological effect. If applied properly these can greatly enhance the appearance as well as the functional suitability of an object.

4.9. DESIGN SPECIFICATIONS AND DRAWINGS

In product design, the last step is the preparation of *drawings* and *specifications.*

Drawings :

- ***Drawings** show the exact size and shape of the product, its different parts and sub-assemblies.*
- The rough sketches made during the product designing are drafted into exact engineering drawings. The drawings show, how the finished parts, sub-assemblies and final product look like when completed.
- Drawings are generally make on standard size drawing sheets in order to facilitate their storage, filing and reproduction.

- A drawing should be kept as simple as possible and be clearly drawn. An ambiguity on a drawing can lead to mistakes.
- An engineering drawing should *include* the following :
  (*i*) Component part number and part description.
  (*ii*) Dimensions from a common datum face to facilitate selling and gauging.
  (*iii*) Tolerances and limits.
  (*iv*) Material details including specifications, size and condition.
  (*v*) Finish description
  (*vi*) Title block.
  (*vii*) Scale and projection.
  (*viii*) Details of any inspection requirements.

Prior to releasing the drawings to the manufacturing section, they should be *checked, approved by the persons concerned* and given the date of issue.

Specifications (Bill of material or part list) :

- Product design features other than physical dimensions are described in writing, in the form of *specifications.*
- The specification is considered as a key manufacturing document. *Specifications provide a written statement of requirements.*
- The industries producing single-unit articles such as forgings and castings can provide all the relevant information on the drawings but those industries which make assemblies need a complete parts list to assist in buying, production control and assembly.

4.10. DESIGNING FOR FUNCTION

The first requirement of any design project is to *deliver a product which measures upto the function specifications.* No amount of other qualities can cover up for incorrect functioning or for insufficient performance.

To be able to design, we must have adequate *technical background.*

Example. For the structural design problem, we should know how to calculate wind loads, how to determine the response of a structure to random vibration of ground during an earthquake and also how to calculate the load capacity of a structure.

Of all the physical quantities that go to define the complete design, some are given as *inputs*, some the designer selects from *data books* and others he *fixes* to give the desired design characteristics. This gives freedom to designer to fix some of these quantities arbitrarily and calculate others. *The arbitrary choice of sense of the parameters thus allows different designs, within the same design concept, measuring upto the specifications.* The choice among these designs is then made on some other criteria. This process is called **"optimisation"** and some of the criteria used are :

— Minimum cost;
— Minimum energy consumption;
— Maximum strength-to-weight ratio;

— Maximum reliability;

— Minimum. number of parts etc.

Since there are usually a large numebr of parameters which need to be fixed, the optimisation becoems hopelessely complex if some preliminary choice is not made. The determination of such parameters is called **"sensitivity analysis"**. The non-critical factors are fixed somewhat arbitrarily and the critical ones are established through mathematical analysis and optimisation to close tolerance.

Another important aspect of design development is to ensure **"compatibility"** in design. In complex systems where the output of one sub-system is the input of the other, compatibility means ensuring that the *different subsystems can interact successfully.*

4.11. DESIGNING FOR PRODUCTION

- When we start to give a physical shape to the obstract concept, we must start considering the question of how it will be produced. A good designer always asks himself the question can this be achieved with the available machines and skills ?
- Every method of manufacture has certain strong and certain weak points. A *good design utilises the strong points of the available manufacturing methods.* It should be obvious that designing for function and production cannot be taken one after the other in a linear fashion. Since the design of a forged component has to be different from a cast component; production considerations have to come right at the beginning of the development phase.

4.12. DESIGNING FOR SHIPPING, HANDLING AND INSTALLING

Whether a large piece of equipment or small consumer item, it needs to be *shipped* from the factory to the user. It must be packed so as to withstand the conditions encountered in transit. These include the handling which the package receives at the time of loading or unloading, the vibration and shock encountered during transit and the humidity and temperature conditions. *It is desirable to design for these at the preliminary design stage.*

In case of products which are conveniently sent by *post*, the overall dimensions must be within the maximum dimensions which the post office accepts for delivery.

— Shipping bolts and screws are often provided on some precision equipment like record players. These are tightened before shipment and are removed when the equipment is installed for operation.

— Portable equipment which has to be carried around by the operator must be so designed that it can easily be lifted. Properly-designed carrying handles should be fixed at points where they ensure the correct weight distribution.

Products which are shipped in unassembled or partly assembled form or which need installation before use require additional attention from the designer.

Wherever possible the design should be such that the assembly is simple and foolproof. The components should be so designed that it is impossible for the customer to assemble it in any but the correct manner. For *example*, three-pin electric plugs have a thick earth pin to permit insertion in the socket is only the correct manner.

4.13. VISUAL DESIGN

- **Visual design** *includes the use of line, form, proportion, texture and colour to produce the eye-pleasing appearance needed to bring about the acceptance of a customer item.* Without this acceptance there would be no profit, and even though the item might otherwise have been carefully engineered, it would soon disappear from the market place.
- As *artistic-styling* is now recognised as being one of the most important factors in sales, many engineers have come to accept the role of stylists in the development of a consumer product, particularly when they are employed by a company that is small and cannot afford to employ one or more trained stylists.

— Now-a-days, design engineers, who have been trained largely to solve technical problems, are reading more about art in design and they are considering the eye-appeal and the overall appearance of products as part of their engineering interests.

QUESTIONS WITH ANSWERS

Q. 4.1. Discuss briefly "Embodiment design".

Ans. Embodiment design *(or product layout) is that part of the design process in which starting from the concept of a technical product, the design is developed, in accordance with technical and economic criteria and in the light of further information, to the point where subsequent detail design can lead directly to production.*

Following are the *general objectives of embodiment design :*

1. Fulfilment of the technical function.
2. Economic feasibility.
3. Individual and environmental safety.

In several cases several embodiment designs or layouts are needed before a definite design found appropriate to the desired solution can emerge.

Q. 4.2. Discuss briefly the statements : "Consider customer assembly" and "Reduce the support costs" in relation to designing a product.

Ans. Consider customer assembly:

- Customer may tolerate completing some of the product assemblies themselves, especially if doing so provides other benefits, such as making the purchase and handling of the packaged product easier.
- However, designing a product such that it can be easily and properly assembled by the most inept customers many of whom will ignore directions, which is a substantial challenge in itself.

Reduce support costs. While making an attempt to minimise the costs of components and the cost of assembly, the team may also achieve reductions in the demands placed on the production support functions.

Examples : • *A reduction in the number of parts reduces the demands on inventory management.*

• *A reduction in assembly content reduces the number of workers reauired for production and, therefore, reduces the cost.*

Q. 4.3. What do you understand by "Maintainability prediction" ? Explain briefly.

Ans. Maintainability prediction *is the process of analytically assessing the maintainability features and calculating the quantitative maintainability characteristics of an item using a defined maintainability model including stated maintenance support conditions.*

"Maintenance tree prediction method" is frequently used to evaluate the maintainabilıty characteristics of a subitem, taking into account the maintenance policy and reviewed reliability data. This method is also useful for trade-offs at design stage. *A "maintenance tree" is a graphic pattern of a complete maintenance operation* (preventive or corrective) *giving qualitative and quantitative information on how to carry out maintenance tasks.*

The *elementary tasks* in a maintenance tree are :

- Dignosis (failure confirmation and localisation);
- Restoration phase (isolation, disassembly, exchange, reassembly),
- Check-out phase.

Q. 4.4. Which maintenance support resources must be adequately provided for cost effective maintainability of any equipment/system ?

Ans. The following maintenance support resources must be adequately provided for cost effective maintainability of any equipment system :

1. Personnel and training.
2. Technical manuals.
3. Test and support equipment.
4. Provision of spare parts.

- A *technical manual* must contain the following :
  — Description.
  — Theory and principle of working.
  — Procedures of operation, testing, fault diagnostics and troubleshooting, repair, service and preventive maitnenance.
  — Reference data. It must cover those tasks which are difficult to perform, frequent faults, influence mission success.

Q. 4.5. Discuss the general conditions which should be taken into account for which 'Preventive maintenance' is appropriate for a single machine.

Ans. The following *general conditions* should be taken into account for which 'Preventive maintenance' is appropriate for a single machine :

1. Preventive maintenance is useful when breakdown time distribution exhibits low variability and when the average of preventive maintenance *(PM) is less than average cost of repair maintenance (RM) after breakdown.*

2. When the machine breakdown results in high idle-labour costs and when preventive maintenance can take place when a production line is normally idle, it is possible to carry out PM than RM.

3. For any complete solution the decision whether to go in for PM or RM will depend upon cost analysis as shown in Figs. 4.1 and 4.2.

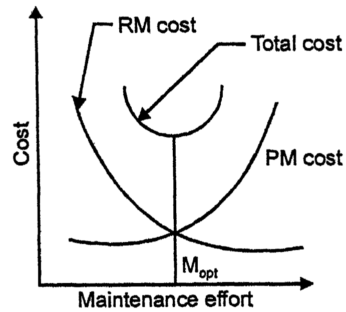


Fig. 4.1.

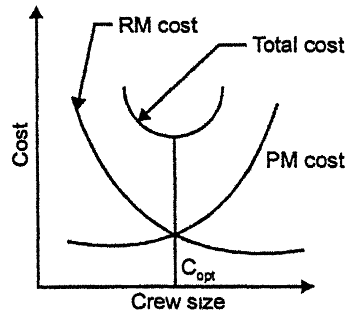


Fig. 4.2.

— In Fig. 4.1. M_{opt} indicates *upper limit of maintenance effort.*

— In Fig. 4.2 C_{opt}. *Indicates optimum crew size for minimum total cost of (RM + PM) costs.*

- In case of a single machine a PM procedure is applied when :
  (*i*) It is a bottleneck machine in a job shop.
  (*ii*) It is a critical machine in a flow shop.

Q. 4.6. What tools can be utilised by the designer to bring out aesthetic characteristic?

Ans. Some of the tools which can be utilised by the designer to bring out aesthetic characteristic are :

1. Use of special materials, either for the parts of the housing or as additional decorations. Notable is the use of chromium strips, plastics, wood, glass and fabrics for the purpose.
2. Use of colour, either natural colour of the material concerned or by use of paints, platings, spraying, or even lighting. Composition and contrast of colours is of great importance to the industrial designer in facilitating convenient operation and attractive appearance.
3. Texture supplements colour, either by appropriate treatment of the given surfaces or coatings. Surface finish and requirements of brightness determined by styling, may in turn affect the production processes in the finishing stages.
4. Shape denoted by outer and similarity to familiar objects. Shape can be exploited to accentuate particular features, to create a sense of spaciousness or illusions of size, richness and dependability.
5. Line is used to break the form, also for the purpose of emphasizing parts of it, or to give a sense of continuity, graciousness and stability.
6. Scaling the product, either to a blownup size or to a small size (modelling). This creates novelty and a sense of completeness. The success of styling of some popular small automobiles in Europe may be partly due to the designer's talent in creating a feeling of still having the full-size version, with all its features.
7. Packaging especially for small items. Novelty and attractiveness of packaging is

often transferred in the mind of the customer. In extreme case, packaging may assume an appreciable portion of the total production costs and become the centre of the design projects.

Q. 4.7. What is the role of aesthetics in product design ? Explain.

Ans.
- While designing a product one cannot leave its appearance out of account, but the degree to which this influences the form depends on the type of product in question. For a certain products, appearance is a basic quality. This applies to for instance to jewellery, clothes and furniture. There are also products where the appearance is immaterial, *e.g.*, carburettors, ferrules, nails and screws. All other products are somewhere between these extremes.
- Beauty is the compliment of ugliness and from this we may get an indication of what beauty is. One must, however, remember that between ugliness and beauty lies the neutral and uninteresting. So beauty must processes other qualities, apart from not being ugly. The most important characteristics are *unity and order.*
  — *A product ought to appear as a finished complete must, where the separate elements and details belong together in a logical and harmonical way.* There must be no elements that stand out as if they did not belong and that arouse questions or surprise. It will also be unfortunate if the product looks as if some part is missing.

It can be generally said that *any disturbance of the overall impression mars the appearance.*

Q. 4.8. What are the characteristic features of system design assembly, sub-assembly design and component design ? Explain.

Ans. When any new product has to be developed from first principles to satisfy a given need, the characteristic features of **system design** are essential. The designer has to have a lot of patience and proceed in a systematic way as per various steps outlined to produce portable models of the product and test its worthiness. Such a procedure is essential for any project.

In **design of assembly/sub-assembly** the *major criterion is the fulfilment of functional requirements.* The assembly has to be designed to meet broad technical parameters and purpose for which it is required. The *characteristic features are :*

(*i*) Minimum number of parts should be used in the design.

(*ii*) Sub-assemblies and assemblies should be capable of being built separately and progressively in order to give the maximum manufacturing flexibility.

(*iii*) Efforts should be made to use standard parts made from standard materials.

(*iv*) Flexible parts should be avoided as they are easily damaged during handling and assembly.

(*v*) Jigs and fixtures should be available for quick testing of necessary dimensions and functioning if possible.

In the **design of component level**, the following points should be carefully *analysed and observed :*

(*i*) Design should be for *minimum material usage.*

(*ii*) Production processes specified should result in the *minimum waste of material.*

(*iii*) Design of product and selection of manufacturing processes must *proceed in parallel.*
(*iv*) Design should be such that the component can be made in the *minimum time.*
(*v*) Limits and tolerances should be as *generous as possible.*
(*vi*) Type of production would depend on the *quantity required.*
(*vii*) In case of large production, necessary *quality control charts should be maintained.*

- The **examples** of system design, assembly design and component design could be designing a *'car', 'engine', 'connecting rod'* respectively.

Q. 4.9. Design of a bus body is required to carry as many passengers as possible from one point to another in a big city. The design should provide comfortable bus journey and the passengers should be able to enter and exit from the bus quickly. Give three conceptual ideas for the design of bus body to solve the problem. Discuss your proposals. Draw sketches wherever necessary.

Ans. In this case *problem has been identified, i.e.,* the **"design of a bus body"**, which is the *"primary design objective", The "secondary design objectives"* are :

(*i*) To carry as many passengers as possible.
(*ii*) To provide comfortable bus journey.
(*iii*) Entry and exit of passengers to be quick.

Three "conceptinal ideas" are discussed below :

First idea. Refer to Fig. 4.3.

- It shows that by restricting the entry and exit, the movement of passengers will be in one direction and will be quick.
- Sufficient number of seats are provided to make the journey confortable.
- A good amount of space is also provided for standing to accommodate maximum passengers.

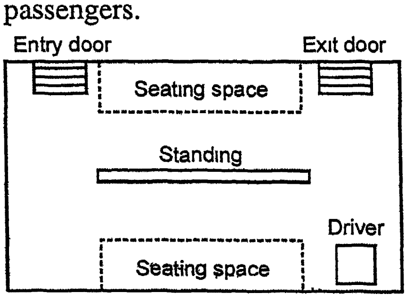


Fig. 4.3. First idea.

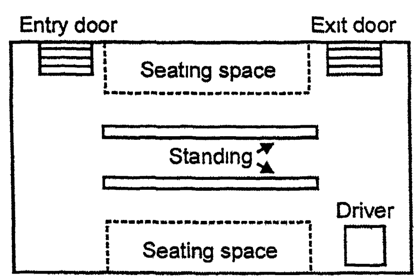


Fig. 4.4. Second idea.

Second idea. Refer to Fig. 4.4.

This concest is modification of the first idea; it reduces the seating space and increases the standing space, thereby accommodating more passengers.

Third idea. Refer to Fig. 4.5.

Here the seating arrangement has been changed to increase the passenger capacity, at the same time providing quick entry and exit (being in one direction).

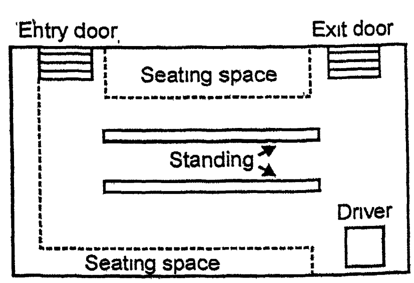


Fig. 4.5. Third idea.

HIGHLIGHTS

1. *Detailed design* is a phase of morphology and is concerned with arriving at final drawing of any product.
2. Manufacturing considerations in design include the following processes :
   (*i*) Primary shaping processes.
   (*ii*) Machining processes.
   (*iii*) Surface finishing processes.
   (*iv*) Joining processes.
   (*v*) Processes effecting changes in properties.
3. The term *Design to Manufacturing (DFM)* may be defined as establishing the shape of components to allow for efficient, high quality manufacture.
4. *Design for Assembly (DFA)* is the best practice used to measure the ease with which a product can be assembled.
5. *Maintainability* is the probability that a device can be restored to operational effectiveness within given period when maintenance action is performed on it in accordance with prescribed procedures.
6. Maintenance may be of the following types :
   (*i*) Routine or periodical maintenance.
   (*ii*) Breakdown maintenance.
   (*iii*) Preventive maintenance.
7. Various concepts of aesthetics for engineering are :
   (*i*) Function.
   (*ii*) Form.
   (*iii*) Unity (harmony).
   (*iv*) Styling.
8. *Visual design* includes the use of line, form, proportion, texture and colour to produce the eye-pleasing appearance needed to bring about the acceptance of a customer item.

OBJECTIVE TYPE QUESTIONS

Fill in the Blanks or Say 'Yes' or 'No' :

1. .... design is a phase of morphology and it is concerned with arriving at final drawing of any product.
2. The processes used for the preliminary shaping of the machine component are known as primary shaping processes.
3. Cold rolling, cold spinning, cold drawing and cold extrusion are various .... working processes.
4. The parting line of a forging should lie, as for possible, in one plane.
5. The forged components should ultimately be able to achieve a .... flow of grains or fibres.
6. Drilling of sloping surfaces should be avoided, while designing a part for easier machining.
7. Abrupt changes of workpiece contours should be avoided to prevent cracking and .... in heat treated parts.

8. A weld should not be located at the point of maximum deformation.
9. Serviceability affects ....
10. Availability is the function of both reliability and ....

ANSWERS

1. Detailed	2. Yes	3. cold.
4. Yes	5. radial	6. Yes.
7. warping	8. Yes	9. maintainability.
10. maintainability.		

THEORETICAL QUESTIONS

1. What do you understand by 'Detailed design' ? Explain briefly.
2. List the steps of the detailed phase of any product.
3. What are the general considerations in designing a machine component ?
4. Discuss briefly the following manufacturing processes relating to manufacturing consideration in design ?
   (*i*) Primary shaping processes (*ii*) Machining processes
   (*iii*) Surface finishing processes (*iv*) Joining processes
   (*v*) Processes effecting changes in properties.
5. List the points which should be considered while designing for the following :
   (*i*) Casting (*ii*) Forging
   (*iii*) Welding (*iv*) Die casting.
6. State the ideal characteristics of a part of an assembly.
7. Discuss briefly the following :
   (*i*) Designing for manufacturing. (*ii*) Designing for functioning.
   (*iii*) Designing for production. (*iv*) Visual design.
8. Define the term "Maintainability".
9. What is the object of maintainability ?
10. Discuss briefly the following terms :
    (*i*) Serviceability (*ii*) Availability
    (*iii*) Trouble free dependability (*iv*) Durability.
11. Discuss briefly the approaches for improving the maintainability of design.
12. What are the factors that contribute to maintainability of an equipment ?
13. How can high maintainability be ensured ? Explain.
14. Discuss briefly the following :
    (*i*) Maintainability during design stage. (*ii*) Plant maintenance.
15. Explain briefly the following types of maintenance :
    (*i*) Routine or periodical maintenance. (*ii*) Breakdown maintenance.
    (*iii*) Preventive maintenance.
16. What do you understand by "Effective maintainability in design" ? Explain.
17. What do you mean by the term 'Aesthetics' ?
18. What are the concepts of aesthetics for engineering ?
19. Briefly explain the basic elements which are used to create an aesthetically satisfying design.
20. What do you understand by "Design specifications and drawings" ? Explain.

❑❑

5

Design Checks

5.1. Introduction; 5.2 Standard sizes; 5.3. Size ranges – General aspects – similarity laws – development of size ranges, 5.4. Reliability – General aspects – factors affecting reliability – methods of achieving high reliability – reliability quantification process – reliability data systems – theory of reliability – reliability of the system – designing for optimum reliability – causes of unreliability – methods for improving reliability – reliability testing; 5.5. Robust design using Taguchi method – General aspects – tools for robust design – achieving quality – Taguchi's seven points; 5.6. Ergonomics – General aspects – applications of ergonomics – human engineering in design – essentials and importance of human factors – models and approaches in ergonomics; 5 7 Standardisation – Introduction – standards – standardisation – definition, advantages, limitations and applications – International standardisation; 5 8. Simplification, 5.9. Specialisation. ***Questions with Answers***—*Highlights – Objective Type Questions – Theoretical Questions*

5.1. INTRODUCTION

Every design is an attempt to fulfill a given function with appropriate layout, component shapes and materials. *The process starts with preliminary scale drawings based on space requirements and rough analysis and proceed to consider safety, ergonomics, production assembly etc.* When a designer deals with these factors, he discovers a large number of inter-relationships.

According to Fohl the following check rules apply to all embodiment designs :

1. Clarity; 2. Simplicity; 3. Safety.

1. Clarity :

— Clarity means clarity of functions or the lack of ambiguity of design.

— This rule facilitates reliable prediction of the performance of the end product and in many cases saves time and cost both.

2. Simplicity :

— Simplicity means not complex, generally guarantees economic feasibility of the product.

— Less number of components and simple shapes are easy to produce and benefits the consumer.

3. Safety

- This rules emphasizes on the problems of strength, reliability, accident prevention and protection of the environment.
- This rules applies for :
  — common safety;
  — functional safety;
  — operator's safety;
  — environmental safety.

Check list for designs. Embodiment design of a product requires a large number of corrective steps before it is finally accepted for production. *It requires evaluations complemented with methods facilitating identification of errors or design faults and optimisation.* Check list of designs is made for finding the defects or flaws in the design at embodiment design stage. The *headings* which find place in check list are as under :

(*i*) Function
(*ii*) Working principle
(*iii*) Layout from design
(*iv*) Safety
(*v*) Ergonomics
(*vi*) Production
(*vii*) Quality control
(*viii*) Assembly
(*ix*) Transportation
(*x*) Operation
(*xi*) Maintenance
(*xii*) Costs
(*xiii*) Schedules.

5.2. STANDARD SIZES

- *The first principle of cost reduction is the use of standard sizes.*
- In order to ensure that standard or preferred sizes are specified, the designer must have access to stock lists of the material he employs. It is advisable to have access to lists, such as those readily available in the market.
- Parts that are made and sold in large quantities usually *cost somewhat less than the odd sizes.*

Tolerances in design :

- *Tolerances in design influence the productivity of the end product in several ways, from necessitating additional steps in processing to rendering a part completely impractical to produce economically.*
- Tolerances cover dimensional variation and surface-roughness range and also the variation in mechanical properties resulting from heat treatment and other processing operations. Since parts having large tolerances can often be produced by machines with higher production rates, labour cost will be smaller than if skilled workers were required.

5.3. SIZE RANGES

5.3.1. General Aspects

- **Size ranges** *provide a rationalisation of design and production procedures.*

- By *size range*, we refer to technical artefacts (machines, assemblies or components) for wide sphere of applications that :
  - — fulfill the same functions;
  - — are based on the same solution principle;
  - — are made of varying sizes;
  - — involve similar production techniques.
- The development of size ranges may be original or based on an existing product but must, in either case, be *carefully graded.*

Advantages of size ranges :

I. ***For manufacturer :***

(*i*) Higher quality is possible.

(*ii*) The design work can be done once and for all and can be used for a host of applications.

(*iii*) The production of selected sizes can be repeated in batches and hence becomes more cost effective.

II. ***For the user :***

(*i*) Short delivery times.

(*ii*) Easy acquisition of replacement parts and fittings.

(*iii*) Competitive and high quality products.

Disadvantages (*Both for manufacturer and user*) **:**

- *Limited choice of sizes, not always with optimum operational properties.*

5.3.2. Similarity Laws

Similarity laws are used very successfully in *"model testing"*. In general, the development of size ranges has a different objective from model technology, namely to achieve :

— the same level of material utilisation,

— with similar materials if possible, and

— with the same technology.

- **Geometric similarity** *ensures simplicity and clarity of design.* The designer knows, however, that technical artifacts stepped up in geometric proportions are not very satisfactory except in rare cases. In particular, purely geometrical magnification is only permissible when similarity laws permit, which should always be checked.
- In case of simultaneous invariance of length and time, we have **kinematic similarity** and in case of simultaneous invariance of length and force we speak of **static similarity**.
- **Dynamic similarity** appears when a constant force relationship is combined with geometric and temporal similarities.
  - — **"Thermal similarity"** deserves special mention because, in the case of geometric similar size ranges and the same utilisation of materials, it *cannot be squared with dynamic similarity.*

5.3.3. Development of Size Ranges

The development of size ranges can be summed up as follows :

1. Prepare the basic design for the range (this can be completely new or derived from an existing product).
2. Determine the physical relationships (exponents) in accordance with similarity laws.
3. Determine the step sizes and add them to the data sheets.
4. Adapt the theoretically obtained ranges to satisfy over-riding standards or technological requirements and record the deviations.
5. Check the product range against scale layouts of assemblies paying particular attention to critical areas for extreme dimensions.
6. Improve and perfect what documentation may be needed to determine the range and prepare production documents (when required).

5.4. RELIABILITY

5.4.1. General Aspects

Reliability is *defined as the probability of a device to perform the purpose adequately for the period of time intended under the operating conditions encountered.*

In present age, the concept of high degree of reliability is essential, as there is too much at stake in terms of cost and human life to take any risks with devices, which might not function properly when used most. Several times redundancy techniques may have to be employed in order to assure better reliability.

The most common measures of reliability are :

(*i*) ***Failure rate*** (expressed in terms of failures per hour, 100 hrs, 1000 hrs or percent failures per 1000 hrs.).

(*ii*) ***Probability of survival*** (expressed as percent which indicates the probable or expected number of devices that will function for a required period of time).

(*iii*) ***MTBF*** (Mean time between failures in hours – It is the ratio of total test time of a device to the total number of failures).

— *Larger the value of MTBF, the greater the reliability.*

- *An effective reliability specification should provide definition of the device or system, means for measurement, evolution, improvement and prediction.* It is also essential to specify :
  — Criteria for adequate performance;
  — Basis for computing time;
  — Description of operating and maintenance conditions;
  — Definition of mal-function and failure;
  — Description of place, methods, instruments, personnel, circumstances, sampling procedures and computation involved etc.

A premature failure will occur due to defect in design or construction of component, even if it has been operated properly.

- *Modern specifications specify the reliability conditions for system in addition to their operation or specific accuracies and performance levels.* Satisfactory performance for reasonable periods of time without failure of machine parts must be ensured, for which it is

essential that reliable materials, through inspection and quality control procedures be adopted in manufacturing them. Sometimes extremely long life is limited by the economic consideration of increased depreciation and maintenance, obsolescence etc.

5.4.2. Factors Affecting Reliability

The reliability of a system (multi-component device) is affected by the following *factors* :

1. Materials and processes used in its manufacture.
2. Service environment and operating conditions.
3. Complexity of construction.
4. Reliability of the individual components.
5. Efficiency of preventive maintenance
6. Quality of repair.
7. Whether or not standby systems are provided.

5.4.3. Methods of Achieving High Reliability

In order *to achieve high reliability for a product, the following points need be considered*:

1. Setting overall reliability goals.
2. Stress analysis.
3. Identification of critical parts.
4. Failure mode and effect analysis.
5. Reliability forecasting.
6. Design review.
7. Reliability testing.
8. Control of reliability during manufacturing.
9. Failure reporting and corrective measures undertaken immediately.
10. Robust design methodology using design of experiments.

- Concepts of design are changing very fast and trend is for least cost, weight and volume of equipment. Though the *best method of achieving a reliable product* is *through* **mature design**, *sometimes it has limitations due to lack of reliable data.* Using too high a safety factor in design is also not good as cost becomes excessive. A designer has, therefore, to resort to *special techniques as well as exhaustive testing* to achieve the required degree of reliability, within the constraints imposed on him.
  — In order to achieve the above objective, the *method of* **reliability prediction**, *and assessing the overall reliability of a device comprising of various parts or components by using statistical techniques is considered to be a good approach.*

5.4.4. Reliability Quantification Process

The reliability quantification process involves the following *three phases* :

1. Apportionment (or budgeting). It is process of allocating reliability objectives among various elements, which collectively make up a higher-level product.

2. Prediction. It pertains to the use of prior performance data plus probability theory to calculate the expected failure rates for various circuits, configurations etc.

3. Analysis. It is the identification of the strong and weak portions of the design to serve as a basis for improvements, trade-offs and similar actions.

- Reliability prediction is a continuous process starting with paper *predictions* based on a design analysis, plus historical failure rate information. The evaluation ends with reliability *measurement* based on data from customer use of the product. Table 5.1 lists some characteristics of various phases.

TABLE 5.1
Stages of Reliability Prediction and Measurement

	1 *Start of design*	2 *During detailed design*	3 *At final design*	4 *From system tests*	5 *From customer usage*
Basis	Predictions based on approximation part counts and part failure rates from previous product usage; little knowledge of stress levels, redundancy, etc.	Prediction based on quantities and types of parts, redundancies; stress levels, etc.	Prediction based on types and quantities of part failure rates for expected stress levels, redundancies, external environ-ments, special maintenance practices, special effects of system complexity, cycling effects, etc.	Measurement based on the results of tests of the complete system; appropriate reliability indices are number of failures and operating time.	Same as step 4 except calculations are based on customer usage data.
Primary use	1. Evaluate feasibility of meeting, a proposed numerical requirement. 2. Help in establishing a reliability goal for design.	1. Evaluate overall reliability. 2. Define problem areas.	1. Evaluate overall reliability. 2. Define problem areas.	1. Evaluate overall reliability. 2. Define problem areas.	1. Measure achieved reliability. 2. Define problem areas. 3. Obtain data for future designs.

* System tests in steps 4 and/or 5 may reveal problems that result in a revision of the "final" design. Such changes can be evaluated by repeating steps 3, 4, 5.

5.4.5. Reliability Data Systems

Reliability data serve the following important *purposes* :

1. To detect current reliability problems and assist in their solution.
2. To provide managers with quantitative information on product performance and the status of the problems.
3. To assist in reliability improvement programs.

4. To provide failure history and other reference data for use in product changes and in future products. This is the data bank concept and serves the needs of reliability in a manner analogous to that served by handbooks of properties of materials (when choosing materials for specific applications).

Reliability data banks. The term *"data bank"* implies an *organised approach to data collection, classification, analysis, summary and retrieval.* Despite the seeming advantages of such an organised approach, it is difficult and costly to execute. In practice, companies make only limited use of the available data. These data originate from :

— Engineering, reproduction, or special test under the manufacturer's control.
— Vendors and major sub-contractors.
— Field performance data, including customer returns.
— Independent data banks.

5.4.6. Theory of Reliability

The discipline of *reliability engineering basically is a study of causes, distribution and prediction of failure.* If *R(t)* is the *reliability* with respect to time *t*, then *F(t)* is the *unreliability* (probability of failure) in same time *t*. Since failure and non-failure are mutually exclusive events,

$$R(t) + F(t) = 1 \qquad ...(5.1)$$

Let, N_0 = Number of components put on test,
$N_s(t)$ = Number of components surviving to or at time t is $N_s(t)$, and
$N_f(t)$ = Number of components that failed between $t = 0$ and $t = t_1$.

Then,
$$N_s(t) + N_f(t) = N_0 \qquad ...(5.2)$$

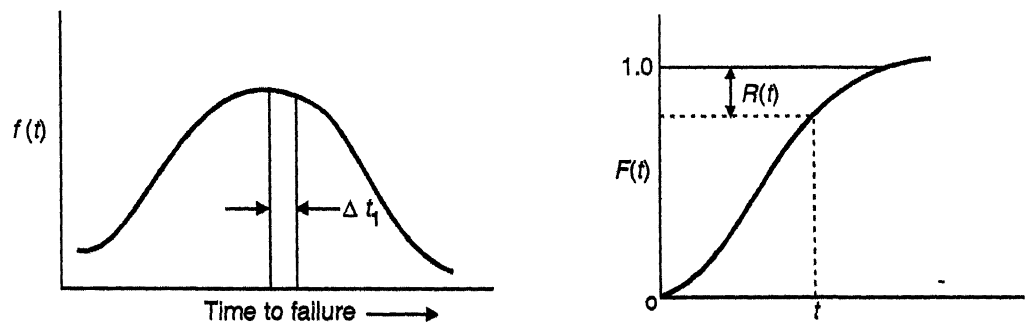
From the definition of reliability, we have

$$R(t) = \frac{N_s(t)}{N_0} = 1 - \frac{N_f(t)}{N_0} \qquad ...(5.3)$$

The hazard rate [$h(t)$], or instantaneous failure rate, is the number of failures per unit time per the number of items exposed for the same time,

i.e.,
$$h(t) = \frac{dN_f(t)}{dt} \cdot \frac{1}{N_s(t)} \qquad ...(5.4)$$

In more statistical terms we can also define the hazard rate $h(t)$ as the probability that a given test item will fail between t_1 and $t_1 + dt_1$ when it already has survived to t_1, (refer to Fig. 5.1).



(*a*) ***Distribution of time to failure*** (*b*) ***Commulative distribution of time to failure***

Fig. 5.1.

$$h(t) = \frac{f(t)}{1-F(t)} = \frac{f(t)}{R(t)} = P(t_1 \le t \le t_1 + dt/t \ge t_1) \qquad ...(5.5)$$

From the nature of statistical frequency distributions,

$$f(t) = \frac{dF(t)}{dt} = \frac{d[1-R(t)]}{dt} = \frac{-dR(t)}{dt}$$

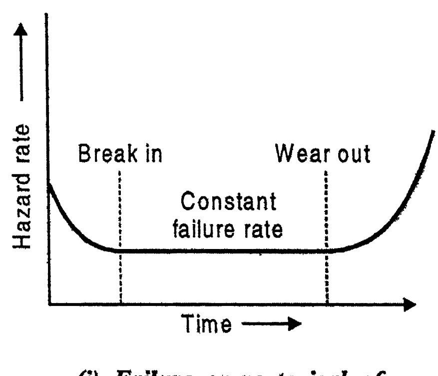
and,
$$h(t) = \frac{f(t)}{R(t)} = \frac{-dR(t)}{dt} \cdot \frac{1}{R(t)}$$

or,
$$\frac{-dR(t)}{R(t)} = h(t) \cdot dt$$

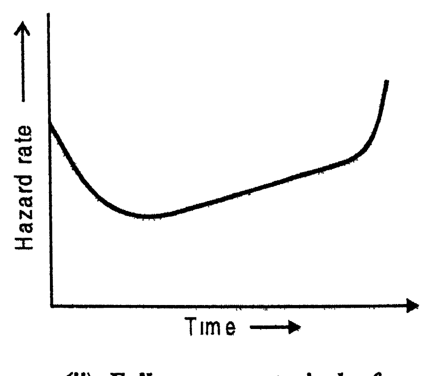
or,
$$\ln(R(t)] = -\int_0^t h(t).dt \qquad ...(5.6)$$

or,
$$R(t) = \exp\left[-\int_0^t h(t).dt\right] \qquad ...(5.7)$$

- The *hazard or failure rate* is given in terms like 2 percent per 1000 h or 10^{-5} per hour. *Components in the range of failure rates of 10^{-5} to 10^{-7} per hour exhibit a good commercial level of reliability.*
  - Another way to define the occurrence of failures is *to state the mean time between failures MTBF).*
- The general forms of the failure curve is shown in Fig. 5.2.



(i) Failure curve typical of electronic components (Bath tub curve)



(ii) Failure curve typical of mechanical components

Fig. 5.2. Forms of failure curve.

— The three-stage curve shown in *Fig. 5.2 (i)* is typical of *"electronic components"*. At short time there is a high failure rate due to *"infant mortality" arising from design*

errors, manufacturing defects, or installation defects. This is a period of *shake down or debugging of failures*. These *early failures can be minimised by :*

(*i*) Improving production quality control;

(*ii*) Subjecting the parts to a proof test before service;

(*iii*) "Running in" the equipment before sending it out of the plant.

As these early failures leave the system, failure will occur less and less frequently until eventually the failure rate will a *constant value*. The time period of constant failure rate is a period in which failures can be considered to occur at random from random loads or random flaws. *These failures follow no predictable pattern*. Finally, after what is hopefully a long time, *materials and components begin to age and wear rapidly and the wear out period of accelerating failure rate begins*.

— The three-stage curve shown in *Fig. 5.2 (ii)* is typical of *"mechanical components"*. In this case, there is *no* region of constant failure rate. After an initial break in period, wear mechanisms operate continuously until failure occurs.

Constant failure rate. For the special case of constant failure rate, $h(t) = \lambda$, and eqn. (5.7) can be written as :

$$R(t) = \exp\left[-\int_0^t \lambda \, dt\right] = e^{-\lambda t} \qquad ...(5.8)$$

For this case, the probability distribution of reliability is a negative exponential distribution.

$$\lambda = \frac{\text{Number of failures}}{\text{Number of time units during which all items were exposed to failure}}$$

The reciprocal of λ, $\overline{T} = \frac{1}{\lambda}$, is *mean time between failures (MTBF)*.

$$\therefore \qquad R(t) = e^{-t/\overline{T}} \qquad ...(5.9)$$

It may be noted that if a component is operated for a period equal to MTBF, the probability of failure is $\frac{1}{e} = 0.37$.

5.4.7. Reliability of the System

The overall reliability of a system (comprising a collection of components) *depends on how the individual components with their individual failure rates are arranged.*

Series reliability. *If the components of an equipment are so arranged that the failure of any one component causes the system failure, it is said to be arranged in* **series**. Reliability of such equipment is determined by *multiplying the individual reliability of each component together*.

i.e., Reliability of the system,

$$R_{system} = R_A \times R_B \times R_C \times \ldots\ldots \times R_n \qquad ...(5.10)$$

where R_1, R_2, R_2, ….. R_n are the reliabilities of individual components A, B, C etc. respectively.

It is obvious that if there are many components exhibiting series reliability, the system reliability *quickly becomes very low.*

Example. If there are 25 components, each with reliability 0.98, the system reliability becomes $= (0.98)^{25} = 0.603$.

- *Most consumer products exhibit series reliability.*

Parallel reliability. A much better arrangement of components is one in which it is necessary for all components in the system *to fail in order for the system to fail.* This is called *"parallel reliability"*. The reliability of the system is,

$$R_{\text{system}} = 1 - (1 - R_A)(1 - R_B) \ldots\ldots (1 - R_n) \qquad \ldots(5.11)$$

- *A system in which the components are arranged to give parallel reliability is said to be* ***redundant***; there are more than one mechanism for the system functions to be carried out.
  — In a system with full active redundancy all but one component may fail before the system fails.

Series-Parallel reliability. Other systems have partial active redundancy, in which certain components can fail without causing system failure but more than one component must remain operating to keep the system operating.

Example. A four engine aircraft that can fly on two engines but would lose stability and control if only one engine were operating. This type of situation is known as *n-out-of-m* unit network. At least *n* units must function normally for the system to succeed rather than only one unit in the parallel case and all units in the series case.

Standby system. Another approach to redundancy is to employ a standby system, which is activated only when it is needed.

Example. An emergency diesel generating unit.

In the analysis of the standby redundant system, the *Poisson distribution is used.*

- On a theoretical basis the use of standby redundancy results in higher reliability than active redundancy. However, the feasibility of standby redundancy depends completely on the reliability of the sensing and switching unit that activates the standby unit. When this key factor is considered, the reliability of standby system is little better than that of an active redundant system.

5.4.8. Designing for Optimum Reliability

The design strategy used to ensure reliability can fall between the following two broad extremes :

- ***"The fail-safe approach"*** *is to identify the weak spot* in the system or component and provide some way to monitor that weakness. When the weak link fails, it is replaced, just as the fuse in a household electrical system is replaced.
- The objective of ***"the one-horse shay"*** (the other extreme) is do design all components to have equal life so that the system will fall apart at the end of its useful life time, just as the legendary one-horse shay did.

— Frequently, a ***"worst-case approach"*** is used; in it the worst combination of parameters is identified and the design is based on the premise that all can go wrong at the same time. This is a *very conservative approach, and it often leads to over-design.*

5.4.9. Causes of Unreliability

The malfunctions that an engineering system can experience can be classified into the following *five* general categories :

(*i*) Design mistakes
(*ii*) Manufacturing defects
(*iii*) Maintenance
(*iv*) Exceeding design limits
(*v*) Environmental factors.

1. Design mistakes. Among the common design errors are :

— Failure to include all important factors;
— incomplete information on loads and environmental conditions;
— erroneous calculations;
— poor selection of materials.

2. Manufacturing defects. Although the design may be free from errors, defects, introduced at some stage in manufacturing may *degrade* it.

Examples :
- Poor surface finish or sharp edges (burrs) that lead to fatigue cracks.
- Decarburisation or quench cracks in heat treated steel.

3. Maintenance. Most engineering systems are designed on the assumptions that they will receive adequate maintenance at specified periods. When maintenance is neglected or is improperly performed, service life will suffer. Since many consumer products do not receive proper maintenance by their owners, a good design strategy is to make the products maintenance-free.

4. Exceeding design limits. If the operator exceeds the limits of temperature, speed, etc. for which it was designed, the equipment is likely to fail.

5. Environmental factors. Subjecting the equipment to environmental conditions for which it was not designed, *e.g.*, rain, high humidity, and ice, usually shortens its service life.

5.4.10. Methods for Improving Reliability

In engineering practice the following *methods* may be used *to improve reliability* :

(*i*) Margins of safety
(*ii*) Derating
(*iii*) Redundancy
(*iv*) Durability
(*v*) Damage tolerance
(*vi*) Ease of inspection
(*vii*) Simplicity
(*viii*) Specificity.

1. Margins of safety. The variability in strength properties of materials has a major impact on the probability of failure, so that *failure can be reduced with no change in the mean value if the variability of the strength can be reduced.*

2. Derating. The analogy to using a factor of safety in structural design is derating electrical, electronics and mechanical equipment. *The reliability of such equipment is increased if the maximum operating conditions are derated below their nameplate values.*

— As the load factor of equipment is reduced, so is the failure rate.

3. Redundancy. One of the most effective ways to increase reliability is with *redundancy*.

- In *parallel redundant designs* the same system functions are performed at the same time by two or more components even though the combined outputs are not required. The existence of parallel paths may result in load sharing so that each component is derated and has its life increased by a longer than normal time.
- Another method of *increasing redundancy* is to have *inoperative or idling standby units* that cut in and take over when an operating unit fails.
  — The standby unit must be provided with sensors to defect failure and switching gear to place it in service.

4. Durability. The material selection and design details should be made with the object of producing a system that is resistant to degradation from such factors as corrosion, erosion, foreign object damage, fatigue and wear. *This usually requires the decision to spend more money on high performance materials so as to increase service life and reduce maintenance costs. "Life cycle costing"* is the technique used to justify this type of decision.

5. Damage tolerance. *A damage-tolerant material or structure is one in which a crack, when it occurs, will be detected soon enough after its occurrence so that the probability of encountering loads in excess of the residual strength is very remote.*

6. Ease of inspection. Ideally, it should be possible to employ usual method of crack detection, but special design features may have to be provided in order to do so. In initially stressed structures special features to permit reliable non-destructive evaluation (NDE) by ultrasonics or eddy current techniques may be required.

— If the structure is not capable of ready inspection, then the stress level must be lowered until the initial crack cannot grow to a critical size during the life of the structure.

7. Simplicity. *Simplification of components and assembles reduces the chance for error and increases the reliability.*

— The simpler the equipment needed to meet the performance requirements the better the design.

8. Specificity. *The greater the degree of specification that is provided the greater the inherent reliability of design. Specifying standard items increase reliability.*

- When it is necessary to use a component with a high failure rate, the design should especially provide for easy replacement of that component.

5.4.11. Reliability Testing

Reliability can be assessed through product testing. During testing, the actual site conditions must be stimulated, so that test results are close to field conditions.

The reliability test data can be used to estimate the reliability as follows :

— Set a confidence on reliability.

— Test the hypothesis that a reliability goal has been met.

Various approaches are based on :

- Exponential distribution.
- Weibull distribution.
- Binomial distribution for success-failure testing.

5.5. ROBUST DESIGN USING TAGUCHI METHOD

5.5.1. General Aspects

*Dr. Taguchi *developed the foundations of* **"Robust Design"** *and validated the basic philosophies.*

— The Robust Design method can be applied to a wide variety of problems :

- Traditionally, the quality has been assured by Statistical Process Control (SPC) – a collection of powerful statistical methods facilitating the production of quality goods by intelligently controlling the factors that affect a manufacturing process. *SPC attempts to achieve quality by reaching to deviations in the quality of what the manufacturing plant has recently produced. Collectively known as the* **Taguchi methods,** *these methods focus on improving the design of manufacturing processes and products.*

Taguchi methods can *help improve process capability. These methods also reduce the sensitivity of the process to assignable causes, substantially reducing thereby the on-line SPC effort required to keep the quality of production on target.*

- The Taguchi methods *lead to superior performance designs, known as* **Robust designs"**.
- The **"Taguchi philosophy"** professes as follows :
  - — The task of assuring quality must *begin with the engineering of quality-product and process design optimisation for performance, quality and cost.*
  - — To be effective, it must be a *team effort involving marketing, research and development, production and engineering.*
  - — *'Quality engineering' must be completed before the product reaches its production stage.*

5.5.2. Tools for Robust Design

The methodology of Robust design serves as an 'amplifier', *i.e.*, it enables an engineer to generate information needed for decision making with half (or even less) the experimental efforts.

In Robust design, the following two important *tasks* are performed :

1. Measurement of quality during design.
2. Efficient experimentation to find dependable information about the design parameters.

1. Measurement of quality during design. It is needed to have leading indicator of quality by which we can evaluate the effect of changing a particular design parameter on the product's performance.

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* Dr. Genichi Taguchi (from Japan) received the individual Deeming Award in 1962 (which is one of the highest recognitions in the quality field), in recognition to his contributions.

2. Efficient experimentation to find dependable information about the design parameters :

- It is difficult to obtain dependable information about the design parameters, so that design changes during manufacturing and customer use can be avoided. Also, the *information should be obtained within time and resources.*
- The estimated effects of design parameters must be valid even when other parameters are changed during the subsequent design effort or when designs of related sub-systems change. This can be achieved *by applying the signal-to-noise (S/N) ratio to measure quality and orthogonal arrays to study many design parameters simultaneously.*

A *'matrix experiment'* consists of a set of experiments where we change the settings of the various product or process parameters, we want to study from one experiment to another. *After conducting a matrix experiment, the data from all experiments in the set taken together are analysed to determine the effect of the various parameters.*

5.5.3. Achieving Quality–Taguchi's Seven Points

The following *seven points* highlight the distinguishing features of Taguchi's approach, which is *aimed at assuring quality :*

1. Taguchi defined the *term* **"quality"** *as the deviation from on-target performance which at first to be a paradox.* According to him, the *quality of a manufactured product is the total loss generated by that product to society from the time it is shipped.*
2. In a competitive economy, Continuous Quality Improvement *(CQI) and cost reduction* are necessary for staying in business.
3. A CQI programme includes *continuous reduction* in the variation of product performance characteristic in their target value.
4. Customer's loss attributable to product performance variation is often proportional to the *square* of the deviation of the performance characteristic from its target value.
5. The final quality and cost (R and D, manufacturing, and operating) of a manufactured product *depend primarily on the engineering design of the product and its manufacturing process.*
6. Variation in product (or process) performance can be *reduced* by exploiting the non-linear effects of the product (or process) parameters on the performance characteristics.
7. *Statistical planned experiments can efficiently and reliably identify the settings of product and process parameters that reduce performance variation.*

5.6. ERGONOMICS

5.6.1. General Aspects

Ergonomics may be *defined* as follows :

"Ergonomics" *may be defined as a science which deals with the systematic study of relationship and interaction between man, machine and working environment."*

—Here by 'environment' we mean not only the ambient environment in which a man works, such as temperature, humidity, noise level, etc., but also his method of work and relationship within the group.

OR

"**Ergonomics** *is an activity which have developed from work study and the aim is to improve the working environment such that the operator fatigue and strain are reduced, and the efficiency as a whole is improved."*

OR

"**Ergonomics** *is also defined as the study of the relation between man and his occupation, equipment and environment, and particularly the application of anatomical, physiological and psychological knowledge, to the problems arising there from.*

- Ergonomics, sometimes called as Human Engineering is an engineering parallel to a field generally referred to as either Industrial Psychology or Experimental psychology.
- Ergon means *Work* and Nomos means *Natural Laws*. Ergonomics or its American equivalent Human Engineering may be defined as the scientific study of the relationship between man and his working environments.
- *Ergonomics* implies fitting the job to the worker. The more modern approach, however, is to fit the job and worker together.
- Ergonomics combines the knowledge of a psychologist, physiological, anatomist, engineer, anthropologist and a bio-metrician.

5.6.2. Applications of Ergonomics

The *applications of ergonomics* are as follows :

1. Ergonomics finds application in the whole field of the *working environment* and deals with such aspects as :

- Anatomical factors in the layout of the workplace, including the design of seats and the arrangement of components and equipment to suit human body measurements.
- The layout and presentation of all types of instrument dials and display panels to help accurate perception.
- The design of control levers, wheels etc. to suit human mental and physical characteristics.
- Lighting, noise and climatic conditions at the work place.

2. Ergonomics also *contributes to the study of energy expenditure, rest pauses, and factors influencing fatigue* and this helps ensure that knowledge, useful in work measurement is kept upto date.

3. Ergonomics has been profitably applied in :

- Design of man-machine systems.
- Design of working environments.
- Design of consumer goods and service systems.

4. In many areas where the critical approach of work study has made an important contribution to the physical or mental well-being of people at work, *ergonomics offers a refinement of approach and a body of new scientific knowledge that enables this contribution to be enhanced.*

5.6.3. Human Engineering in Design

In human engineering there are a number of factors, other than human anthropomeric measurements, that must be dealt with in design. These *factors include* :

— Motor activity and body orientation;

— The five human senses (sight, hearing, touch, smell and sometimes even taste);

— Atmospheric environment, temperature, humidity and light;

— Accelerating forces if they are exceptional and are likely to cause undue physical discomfort.

- Human engineering is applied to a wide range of consumer items. Automobiles, refrigerators, furniture, office equipment, lawn movers, hand tools and like items have long been designed with human factors in mind.
- Under pressure from consumer groups and organisations interested in safety and in protecting our natural environment, there has been a rising tide of governmental laws and regulations. Many of these new laws and directives in a sense provide controls in the field of human engineering.

These government laws have come into existence because of a growing interest on the part of the general public in human engineering. Designers in the years ahead must be fully cognizant of all such regulations and must be willing to abide by them or seek to have them changed, should they appear to be unreasonable or impractical.

5.6.4. Essentials and Importance of Human Factors

Essentials of human factors. The main essentials of human factors are :

1. *It is a process of integration:*
   — Integration means to unite, combine and form a compositive effective whole.
   — There must be an integration of interests and attitudes of the employer and employees and there should be no diversity of interest of each person with the interest of all others in the organisation.

2. *Willingness to work :*
   — The principal objective should be to secure the willing cooperation of the employees.
   — With the sincere effort on the part of the management, the workmen may be motivated to offer their willing cooperation for achieving the target of greater, better and cheaper production.

3. *Stress on human aspect :*
   — Management should stress on the human aspect of labour and workers should be treated as human being within and outside the workplace. Money is not the only thing, they want, but the human treatment is the main motto.

4. *Social aspects :*
   — Satisfaction of all types of needs (*i.e.*, economic, psychological and social needs) of the workers in an implied condition in "human relations approach."

Importance of human factors. The human factor in industry can be justified on the following grounds :

1. *Human engineering can streamline production :*
   — Human factor is the most pervading force which is responsible for success or failure of the organisation.
   — Industry is not composed of machines, finance or material only. All are nothing, without the efforts of human beings.
2. *Moral justification :*
   — Workers are human beings and therefore must be given a humanly treatment.
   — They should be treated with the same respect for their dignity, that any other human being can claim.
3. *Place of human factor in industry :*
   — The place of human factor in industry and business cannot be overemphasized. For better relations, good human relations are necessary.
   — Efficiency and ability of workers much depend upon the human relations.
4. *Wider scope :*
   — The importance of human relations is not only for the production units but other spheres of life also require good human relations. It is not a technical problem, it is human, social or moral problem and humanity should be developed technically.

5.6.5. Models and Approaches in Ergonomics

The most general approach to ergonomics is to *think of a person interacting with a machine.* This interaction is made by means of *displays* by which the machine passes information to the machine (Fig. 5.3). Thus, there is a complete information flow loop, all parts of which must function properly and which must not cause any delays in the flow information if successful, safe and efficient use is to be achieved.

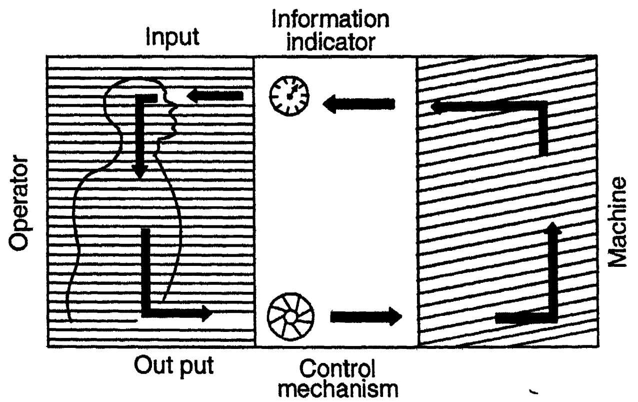


Fig. 5.3. Communication between user and machine.

The interaction between user and machine, in all cases, takes place within some *workspace*, which itself is located in an *environment. The characteristics of the workplace and the environment will affect the performance of the task.*

— The *"workplace"* is described in terms of the size and layout of chassis, tables and desks, consoles, gangways and other equipment. These will affect the position, posture and reach of the expected range of users and hence their comfort and efficiency.

— The *"environment"* may be described in physical terms, such as, climate, lighting, noise and vibration and the presence and effect of chemical and biological agents; and in psychological terms, such as work team and command structure, shift conditions, psychological factors and so forth.

The system approach :

The object for which any user machine system is designed will be achieved only if all its components are matched to each other and interact in ways appropriate to their common purpose. A car speedometer which will serve its purpose for ten years might be thought to be better than one which will do so for only five years but a component of low priced car which is itself designed to last for five years, the second instrument will be better since it will be cheaper.

System design *differs from engineering design in the importance it attaches to the human operator as an integral part of the system to be designed, and in the emphasis it lays on the suitability of all components for the functions to be allocated to them for the achievement of the overall objective.*

Fig. 5.4. illustrates the 'System design process'.

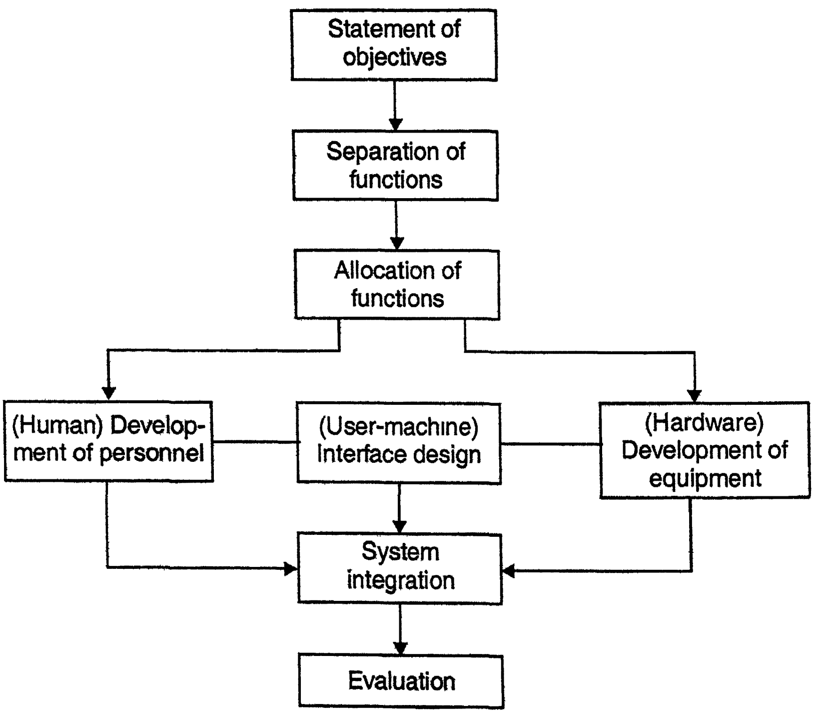


Fig. 5.4. The 'Systems design process'.

5.7. Standardisation

5.7.1. Introduction

- *To standardise means to confirm to certain uniform specifications; standards give products or parts of certain known characteristics.*
- Standardisation includes the basic principles of *simplification*; that is, a reduction of sizes, style and special features. However, it embodies much more. Standardisation is applied to size and form of manufactured products.
- There are standards of excellence or quality, engineering and production standards, standard materials, standard methods and performances, standard tools, standard conditions, and many other types of standards.
- Standardisation is an attempt towards uniformity in terms of these features so that the buyer of a product or the user of tools, materials, etc., will be able to evaluate them prior to their purchase or use.
- Through standardisation a manufacturer may be able to reduce the number of parts required in his assembly and his investment in tools and inventory. Through standardisation it may be possible for a manufacturer to carry on diverse production without encountering the increased costs of diversification. To the extent the new products are developed largely through a different combination of standard parts, production economies of simplification can be largely retained.

5.7.2. Standards

A **standard** *may be thought of as an established measure, something to strive toward, a model for comparison, a means by which one thing may be compared with ...."*

- *Standards provide norms or reference lines for management.* That is to say, through standards a manager is supplied the means for identification, comparison, achievement and the determination of whether a factor is above, below or on par with an established and accepted base of that factor.
- A standard is determined as a result of scientific study of the essential qualities or characteristics, that must be present in a product.

Objects or purposes of standards :

The *broad purposes of standards* are :

(*i*) To describe products, processes and activities.
(*ii*) Identification.
(*iii*) To assist in measurement.
(*iv*) Uniformity of product.
(*v*) To assist in settling disputes.

Sources of standards :

1. Government standards.
2. Professional groups and trade association standards.
3. Company standards.
4. Commercial standards.

5.7.3. Standardisation–Definition, Advantages, Limitations and Applications

Definition :

Standardisation *is the process of establishing standards or units of measure by which extent, quality, quantity, value, performance, may be compared and measured.*

Standardisations means the voluntary fixation of standard dimensions, equipment, quality and practice, with a view to having a large production of only a limited number of varieties. Standardisation is applicable to all factors of productions like men, machine, money, materials, markets and methods.

The object of standardisation is to measure, to identify, to compare or to describe products, processes, activities and performance in an organisation.

Standardisation is the *basic task* in the control function of management and expedites the management work of guiding and directing performance in the business unit. It plays its own vital role in the 'Design development', providing numerous advantages to the procedure.

Advantages of standardisation :

Regardless of the nature of standardisation — whether it pertains to size, quality or quantity — there are certain *inherent advantages* that accrue to business and society.

1. It removes the possibility for misunderstanding between the maker and the user of a product. When a buyer asks for a brass bushing having a 32 finish, he is sure to get what he wants, because this degree of smoothness has been specifically defined in smoothness standards adopted throughout the country.
2. It is easy to evaluate standardised product.
3. It improves business operations.
4. It results in lower costs of output.
5. It simplifies the buying function.
6. It lubricates the mass method of selling.
7. It simplifies methods of financing.
8. It facilitates as well as cheapens replacements. This results in cheaper and easier maintenance and repairs.
9. It eliminates unnecessary costs concerning drawing, designing and planning.
10. It enables interchangeability and easy assembly which is the key of large scale production.
11. It may be an indirect advantage in that it forces manufacturers to develop significant differences in their products.

Disadvantages :

1. It becomes *difficult to introduce new models* because of less flexible (existing) production facilities and due to the high cost of specialised production equipment.
2. *Reduction in choice* because of reduced variety and consequent loss of business or custom.
3. Changes in public taste *seriously affect* a company producing only standardized product range.

4. Standardisation *tends to favour large famous companies*, because small or new concerns can rarely get much business even by producing same items and by selling them at the same price as the big companies.

Standards once set, resist change and thus standardisation may become an obstacle to progress.

- The *extent of standardisation should be decided through a formal market study.*

Applications of Standardisation :

Standardisation can be applied to a major extent in the following fields :

1. Finished products, *e.g.*, cars and televisions.
2. Subassemblies and components, *e.g.*, automobiles gearboxes and auto-electric bulbs.
3. Material standardisation, *e.g.*, both of direct materials (plain carbon and alloy steels, arc welding electrodes, core wires etc.) and indirect materials (such as oils and greases).
4. Production equipment standardisation, *e.g.*, that of machine tools, presses, welding equipments etc.

5.7.4. International Standardisation

The following points relating to 'International standardisation' are worth noting :

1. It becomes very necessary to follow international standards, if a country has to capture the export market.
2. The work of international standardisation is carried out under the guidance of ISO (International Organisation for Standardisation).
3. Most industrialised countries are members of ISO.
4. ISO was founded after World War II.
5. ISO does not issue independent standards of its own but it makes recommendations, which are included in the National Standards of the collaborating countries.

- Every country has its own national standards. IS in India, BS in UK, DIN in Germany are few examples of national or home standards.

5.8. SIMPLIFICATION

Introduction :

- The term ***"Simplification"*** *connotes the elimination of excess sizes, varieties, styles, dimensions, process and the like, based primarily upon observation and experience.*
- It is not as exacting as standardisation and can be throughout of as the *weeding out of superfluous variety in an existing product*. The need for simplification is felt when we see unnecessary complexity or confusion. In industry, for example, needless complexity and cost may result from the large number of products offered by a firm in its attempt to market a "full line". In simplifying such a producing line we would not attempt to eliminate products simply

to reduce the quantity offered. Instead, this application of simplification would be to *remove the unnecessary products those seldom if ever desired by the consumer.* Product simplification, therefore, is *directed toward reducing losses resulting from undesirable variety, thereby making business more efficient.* Thus when the management of a company thinks that a great many of its products are either no longer required or infrequently used by its customers, it may well undergo a simplification programme to eliminate the superfluous products from its line.

- Simplification may also be undertaken from a product design stand point. It may also be applied to work methods and processes. The objective here is *to eliminate the number of wasted operations and motions employed in producing a product.*

Advantages :

The advantages of *'simplification'* can be summed up as follows :

1. With fewer parts and varieties, fewer machine changes will be needed and fewer raw materials will be required.
2. It results in less obsolescence of machinery as well raw material.
3. With a reduction in parts also comes a reduction in operations, thereby enabling management to standardise and specialize work, making for simpler, easier work methods.
4. When excess variety is reduced, the volume of remaining products can be increased, often at lower costs.
5. Frequently, simplification makes for a more nearly even manufacturing pace and employment and results in better consumer service.
6. Simplification modifies sales techniques and makes sales force more efficient. Sales are secured on quality according to relative price and not on just novelty.
7. Financing becomes easy.
8. The products produced are of better quality because the producers can concentrate effectively on fewer and better signs.
9. The employees become more efficient because their training in one particular job gets very much simplified.

5.9. SPECIALISATION

Specialisation *is the devotion of particular productive resources exclusively to the manufacture of a narrow range of products.* The extent of specialisation to be effected depends on type of product, type of the market etc. *Specialisation of product is the ultimate objective of variety production. Specialisation is the natural outcome of the application of standardisation and simplification.*

Product specialisation aims to achieve higher productivity through the use of standardised method of manufacturer. It leads to increased output and thereby reduces cost of the finished product. It leads to manufacturing the quality products and saving in material purchase.

Advantages, limitations and applications :

Following are the *advantages, limitations* and *applications* of specialisation :

Advantages :

1. Workers achieve a high state of skill and proficiency.
2. Workers take smaller times to complete the activities in which they are specialised. Consequently their salaries get raised and hence their standard of living.

Limitations :

1. Specialisation may result in monotony.
2. Specialised labour and equipment are not flexible, *i.e.*, they cannot be used for other purposes.

Applications :

1. Specialisation is universal in application; it is a rule rather than exception in today's industry.
2. Specialisation has been applied to :
   — Products;
   — Processes;
   — Individuals;
   — Companies;
   — Jobs;
   — Equipments etc.

QUESTIONS WITH ANSWERS

Q. 5.1. What is Taguchi method? How does it find its application in reliability and robust design?

Ans. Taguchi methods. Now-a-days ***"Quality"*** *means meeting agreed customer requirements fully first time, every time and time after time.*

To manufacture a product and to impart services that meet customer's standards, quality is traditionally assured by *'Statistical Process Control' (SPC).*

"Taguchi's methods" are the collection of powerful statistical methods facilitating the production of quality goods by intelligently controlling the factors that affect a manufacturing process.

Applications of Taguchi's methods for 'Reliability' and 'Robust Design':

1. Taguchi has argued that whenever the *performance of a product deviates from its target performance, society suffers a loss. The manufacturer suffers a loss when he repairs or rectifies a rejected product not measuring up to its target performance. The customer incurs a loss in the form of inconvenience, monetary loss, or a hazardous consequence of using the product.*

2. Aiming for parts and products to conform to the specification limits will only lead to production of mediocre (average) quality product. In a competitive world, customer is not satisfied

with mediocre quality. He is looking for an *excellent quality product*. Excellent quality is achieved only when *we aim for perfection during manufacturing where parts and products are produced very much close to the target and not confined only to meeting the specification limits.*

During product design nearly 80% of the limetime cost of a product becomes fixed once its design is complete.

- Products are designed to give a *target level of performance*. These targets are set based on the need to satisfy the customer. Product and process design requires a systematic development, progressing stepwise through system design, parametric design, and finally tolerance design. The design engineer starts out with targets for parts and sub assemblies and then adds tolerance limits (specifications) to facilitate manufacturing. The use of tolerance rather than targets in manufacturing results in actually operating over the entire tolerance range, leading to tolerance stack problems. Tolerance stack up in such a manner that the final product fails to meet specifications even when all parts are within their individual tolerance limits. As per Taguchi, *"meeting the target is more important than confirming to specifications limits and our aim should be to reduce variability to zero, which will result in the production of consistent quality product."*
- The *Taguchi philosophy professes* that the task of *assuring quality must begin with the engineering of quality-product and process design optimization for performance, quality and cost.* To be effective, it must be a team effort involving marketing, research and development (R&D), production and engineering.
  — *'Quality engineering' must be completed before the product reaches its production stage.*

Thus the application of Taguchi statistical methods off-line (before production) which precede on line Quality Control (QC) done during manufacturig leads to superior performance designs known as robust designs.

Q. 5.2. List the reasons why methods of 'Robust design' can aid in successful commercialization of products and processes.

Ans. Robust design *means that the product is so designed that small variations in production or assembly do not adversely affect the product.*

Reasons which aid in successful commercialisation of products and processes applying robust design are :

1. Robust design reduces research and development cost.
2. Robust design reduces production cost of product and process both.
3. Robust design allows continuous improvement in quality of product, which is necessary to stay in business.
4. Variation in product (or process) performance can be reduced by Robust design using non-linear effects of the product (or process) parameters.
5. Statistically planned experiments can efficiently and reliably identify the setting of product and process parameters that reduce performance variations.
6. As in robust design, inspecting, appraising and evaluating the quality of products go out of line, a large sum of money spent for doing these is saved.

7. Robust design can be produced to requirements even with unfavourable conditions in the production.

Q. 5.3. (a) Compare the reliability of systems with components in series versus components in parallel.

(b) In a system there are 10 components in series each with a reliability factor of 0.95. What is the overall reliability of the system?

(c) If each of the 10 components is in parallel and has individual reliability factor of 0.30 only, what is the system reliability?

Ans. (a) It would seen that while reliability of system with components in series is obtained by multiplying the individual reliability of each element; in case of parallel system, the unreliability of system (1-reliability) is obtained by multiplying unreliability of each compoent.

(b) Reliability of each component = 0.95

Sicne there are 10 components in series, overall reliability of the system,

$$R_{system} = (0.95)^{10} = \mathbf{0.5987.\ (Ans.)}$$

(c) Reliability of each component = 0.30

Unreliability of each component = 1 – 0.30 = 0.70

Since components are in parallel, *unreliability of system* = $(0.70)^{10}$ = 0.02825

$\therefore$ System reliability, $R_{system} = 1 - 0.02825 = \mathbf{0.97175\ (Ans.)}$

$$\left[\textit{Alteratively}: R_{system} = 1 - (1-R)^n = 1 - (1-0.30)^{10} = 0.97175,\ \text{where R is the reliability of each component and } n \text{ is the number of components}\right]$$

Q. 5.4. Discuss briefly the main causes of unreliability of an engineering system. How the reliability can be improved?

Ans. Following are the two *causes* of unreliability of an engineering design system :

(i) Stochastic nature of loads and external environmental factors.

(ii) Variation of material property.

- *Reliability can be improved by keeping a good safety factor and using consistent material.*

Q. 5.5. What are the risks of poor product reliability to customer as well as the producer? Explain.

Ans. *Risk* is the probability of risk of a totality per person per year or per hour exposure by use of product. Poor reliability of any product means chances of failure of product are more; under poor reliability the risks are as under :

Risk to customer :

(i) Financial losses.

(ii) Accidents, which may lead to health hazard.

(iii) Time loss which depends upon type of product, he or she is using.

Risk to manufacturer :

(*i*) Financial loses, which may occur due to sale.

(*ii*) Time lose in redesigning product for better reliability.

Q. 5.6. Discuss briefly the influence of reliability on cost.

Ans. *Reliability costs money, but the cost nearly always is less than cost of unreliability.* The cost of reliability comes from extra costs associated with designing and producing more reliable components, testing reliability and training and maintaining a reliability organisation.

Fig 5.5 shows the influence of reliability on cost.

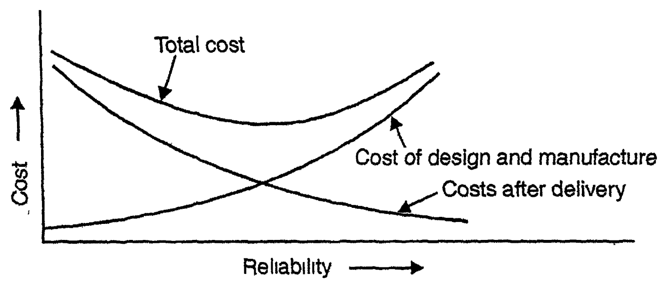


Fig. 5.5. Influence of reliability on cost.

— The costs of design and manufacture increase with reliability. Moreover, the slope of the curve increases, and each incremental increase in reliability becomes harder to achieve.

— The cost of product after delivery to the customer, chiefly warranty or replacement costs, etc. decrease with increasing reliability.

— The summation of the curves produces an optimal level of reliability.

Other types of analyses establish the optimum schedule for part replacement to minimize cost.

Q. 5.7. What are the methods of achieving reliability of any product?

Ans. The *methods of achieving reliability of any product are as under :*

1. Improve design of components.
2. Simplify design of system.
3. Improve production techniques.
4. Improve quality control.
5. Test components and the system.
6. Install standby or parallel system.
7. Perform periodic prevention maintenance.
8. Derate components and the system (Derating a system means do not needlessely overload the system rather, underload the system or product.)

Q. 5.8. Explain briefly the procedure for assessing design reliability.

Ans. The following ***steps*** are involved in the procedure for assessing design reliability :

1. *To establish the 'problem statement' or 'system definition'.*

—This should lay out the criteria for success or failure of the design, the performance

expected, the environmental factors, duty cycles, and all boundary conditions and physical constrains on the design.

2. *To draw a reliability block diagram of the system.*
   —This diagram will be similar to the functional block diagram, which may be part of the problem definition, but it will stress those areas which influence reliability.
3. *To prepare a list of parts* in each block of the reliability block diagram.
4. *To collect data on failure and performance* for each part or component.
   —The data will come from company records, user data banks, military sources, and the general technical literature.
5. *To calculate the hazard rate or failure rate* for each component with the aid of the data that has been collected.
   —Often extensive plotting of data and analysis is required.
6. *To combine the failure rates* (after knowing the failure rate for each component in each block of the reliability block diagram) *to calculate the failure rate of each block.*
7. *To compute the system reliability* (with above information), *its failure rate and the mean time between failures.*

Q. 5.9. What is "Exponential formula for realibility"? Explain briefly.

Ans. The chance of obtaining failure-free operation for a specified time period or longer can be shown by changing the TBF (Time between failures) distribution to a distribution showing the number of intervals equal to or greater than a specified time length. The distribution of time between failures indicates the chance of failure-free operation, for the specified time period. If the prequencies are expressed as relative frequencies, they become estimates of the probability of survival.

When the failure is constant, the *probability of survival* (P_s) or reliability (R) is

$$P_s = R = e^{-t/\mu} = e^{-t\lambda}$$

where, $e = 2.718$,
t = Specified period of failure-free operation,
μ = Mean time between failures, or MTBF (the mean of TBF distribution), and
λ = Failure rate (the reciprocal of μ).

It may be noted that this formula is simply the exponential probability distribution, rewritten in terms of reliability.

Q. 5.10. What do you understand by "Reliability allocation"?

Ans. ***Reliability allocation*** *is the process of assigning reliability requirements to system parts or components to achieve the overall specified reliability of a system.*

A system could be considered as composed of subsystems forming a series configuration (If one sub-system fails, the entire system will fail). The failure rates of subsystems are supposed to be constant and sub-system failures independent. Further subsystem mission times are equal to the system mission time.

Q. 5.11. An automobile tyre has four independent and indentical tyres. If any one of these flattens, then the vehicle cannot be driven. Calculate the probability of the automobile failing to operate due to a flat tyre. Also, if the reliability of each tyre is 0.92, what is the reliability of the automobile with respect to tyres?

Ans. *Given*: Number of identical tyres, $n = 4$, and

Reliability of each tyre, R = 0.92

This problem represents a four independent unit *series* system (the vehical tyres are the units of the *series* system).

Since all the tyres are *identical*, the reliability of the system,

$R_S = R^n$

$R_S = (0.92)^4 = 0.7164$

Thus, the *"reliability of the automobile with respect to tyres"* = **0.7164 (Ans.)**

Now, the **"probability (P_s) of the automobile** *failing to operate due to a flat tyre"* is given by,

$P_S = 1-R^n = 1-(0.92)^4 \; 1-0.7164 =$ **0.2836 (Ans.)**

Q. 5.12. An aircraft has three identical independent engines that function simultaneously. At least one engine must operate successfully for the aircraft to fly successfully. If the reliability of each engine is 0.85, calculate the probability of the aircraft flying successfully.

Ans. *Given* : Number of identical engines in the aircraft $n = 3$

Reliability of each engine, R = 0.85

∴ The *reliability or probability of the aircraft flying successfully* is,

$R_p = 1 - (1 - R)^n$

$= 1 - (1 - 0.85)^3 =$ **0.9966** or **99.66% (Ans.)**

Q. 5.13. Calculate the probability of survival of a piece of equipment that is to operate for 500 hours which consists of four sub-assembly systems having the following MTBFs:

Sub-system A – MTBF = 5000 hours

Sub-system B – MTBF = 3000 hours

Sub-system C – MTBF = 1500 hours

Sub-system D – MTBF = 1500 hours

Ans. Reliability of sub-system A, $R_A = e^{\left(\frac{-500}{5000}\right)} = 0.9048$

Reliability of sub-system B, $R_B = e^{\left(\frac{-500}{3000}\right)} = 0.8465$

Reliability of sub-system C, $R_C = e^{\left(\frac{-500}{1500}\right)} = 0.9672$

Reliability of sub-system D, $R_D = e^{\left(\frac{-500}{1500}\right)} = 0.9672$

● If the sub-assembless are in *series*,

$R_s = R_A \cdot R_B \cdot R_C \cdot R_D = (0.9048)\,(0.8465)\,(0.9672)\,(0.9672) =$ **0.7165 (Ans.)**

- If the sub-assemblies are in *parallel,*

$R_p = [1 - (1 - R_A)(1 - R_B)(1 - R_C)(1 - R_D)]$
$= [1 - (1 - 0.9048)(1 - 0.8465)(1 - 0.9672)(1 - 0.9672)]$
$=$ **0.9999843 (Ans.)**

Q. 5.14. Discuss briefly the various types of failures.

Ans. The following three types/categories of failures are normally encountered :

(*i*) Break in or initial failure.
(*ii*) Wear-out failures.
(*iii*) Chance failures.

1. ***Break in or initial failure.*** These arise because of *manufacturing faults*, which somehow escape inspection.

- These can be easily taken care of by carrying out *burn-in test or debugging in shop* before despatch of equipment. Such type of failures get revealed during burn-in test or debugging and can be replaced with healthy parts.

2. ***Wear-out failures.*** There occur *after the product has put in its design life.*

- These are taken care of by following *preventive maintenance procedures*, so that such components are replaced before they actually fail when their life is nearing completion.

3. ***Chance failures.*** These refer to *premature failure to which no cause can be readily assigned.* It is a cause of real worry for the designer.

- The designer can control it only in the sense that *he can regulate its rate of occurence to some extent, by determining its reliability.* The reliability of a product is measured by the rate of occurrence of the chance failures. The reliability for time '*t*' is defined as the probability of the survival of a system through time '*t*'.

Fig. 5.6 shows how number of failures increase with time, the three types being shown by zones I, II, and III.

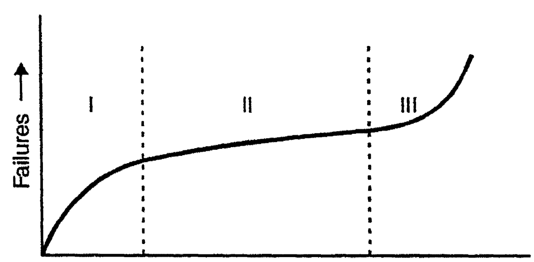


Fig. 5.6

Q. 5.15. Explain the bath-tub life characteristic curve for a product reliability.

Ans. *Failure (hazard) pattern of equipment—Both tub curve :*

Fig 5.7 shows the failure (hazard) pattern of equipment consisting of several components.

In the initial troubleshooting stage time to t_1, the instantaneous failure (hazard) rate λ is much higher than in the middle portion of the graph when it is λ_a, due to failure in components which later occurs at random overtime. When a component fails; it is immediately replaced by another

and the equipment continues to run as before. For a long period of time during the life of the equipment, say from time t_1 to t_2 these failures, called *"accidental failures", occur at a constant rate*. After a period t_2 when the equipment gets old and worn out, the failure rate again moves to higher levels.

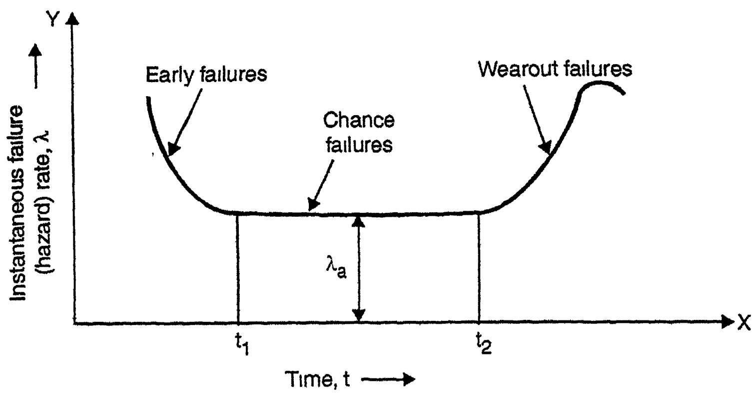


Fig. 5.7. Bath tub curve

The graph shown in figure which is plotted with time on X-axis and the instantaneous failure rate in Y-axis is called ***"Bath tub curve"*** owing to its shape.

Q. 5.16. What is 'Hazard analysis'? Explain briefly.

Ans. ***'Hazard analysis'*** *relates to "techniques" which have been developed to identify potential causes of failure, rate them in terms of criticality and establish the conditions under which the failure has the greatest likelihood of occurrence and/or the gravest consequence.*

- The *"preliminary hazard analysis"* is a broad study made in the early stages of design. It consists of breaking the engineering system down into subsystems or assemblies, or even to individual components, and for each item answering the following *questions* :
  1. Subystem or item under investigation.
  2. Mode of operation.
  3. Hazardous element.
  4. Event that triggers the hazardous condition.
  5. Hazardous codition.
  6. Event that triggers the potential accident.
  7. Potential accident.
  8. Possible effects of the accident.
  9. Measures taken to contain or prevent occurrences.
  10. Classification of the severity of the hazard.

Information to complete the hazard analysis comes from such sources as :

— Personal experience.
— Interviews with operating personnel, and operating supervisors;
— Failure report forms;
— Published literature.

- *"Failure modes and effective analysis"* (FMEA) *is a detailed analysis of the malfunctions that can be produced in the components of an engineering system.* The emphasis is less on identifying hazards and potential safety problem and more on how to redesign the components to increase system reliability.
- *"Fault hazard analysis"* was developed by safety personnels to be sure that all categories of hazards are inculded in the analysis. *It is a qualitiative method and does not require the estimation of probability of failure. It can be considered more as an extension of the preliminary hazard analysis.*

Q. 5.17. Explain why we perform following analysis :
1. Component analysis;
2. Performance analysis;
3. Reliability analysis.

Ans. 1. **Component analysis.** Necessary part of embodiment analysis is to evaluate *components* to be used in product. Then comes the *material, quality* and *standard.*

Component analysis serves the following purposes :

- It acts as important tool to verify the use and required necessity of the component in the product, its cost and other feasibility factors.
- It can help to reduce the cost of components and product both.
- It can improve the life of the product.

2. **Performance analysis :**

- This analysis is done to ensure that the proudct is *able to withstand the technical and other functions* assigned to it.
- This analysis is also a *necessary step* before launching the product in the market, as if, the performance is not as required.
- This analysis is *mainly done to know the performance of components and product on specified specifications.*
- This analysis also helps in *searching and locating the weak spots of the product.*

3. **Reliability analysis :**

- Reliability analysis of a component on a device *gives the defects and prediction of failure of such component or device.*
- This analysis also gives information about faults in design process, manufacturing defects etc.

All the above three analysis are the tests for performance, failure rates and types of components to be used in a product to achieve success in product development.

Q. 5.18. What kinds of costs are associated with machine breakdown? Discuss the general methods by which the reliability of production system can be maintained.

Ans. *Costs associated with machine breakdown are :*

(*i*) Loss due to breakage of component or part.
(*ii*) Loss due to production loss (due to machine downtime).
(*iii*) Cost incurred in repair in case the breakdown part can be repaired.
(*iv*) Loss due to inability to meet production schedule.
(*v*) Cost incurred for payments to maintenance personnel.

- The various way to *improve "system reliability"* are :

(*i*) ***Improved component design.***

— This can be achieved by improvement in production techniques.

(*ii*) ***Simplification of system design.***

— This can be achieved by improved quality control.

(*iii*) ***Testing of components and system.***

— This can be performed by installing parallel configurations.

(*iv*) ***Perform periodic preventive maintenance.***

— This can be achieved by derating system load below design value.

Q. 5.19. What is ergonomics? Give four examples where ergonomics considerations have improved or can improve product design and utility.

Ans. *Ergonomics is a science which deals with the systematic study of the relationship and interaction between man, machine and working environment.*

Considerable part of ergonomics deals with human behaviour which covers a number of human factors which are liable to effect the ultimate output of a production unit, which is regarded as an integrated system of man and machines, within the envelope of environment. Ergonomics therefore relates to :

- **Himself :**

— His ability;

— His limitations;

— His capacities.

- **His relationship with :**

— His fellow workers;

— His superiors;

— Management;

— His family.

Typical examples of ergonomic design are as follows :

1. Mopeds
2. Chains
3. Toothbrush with novel shape
4. Machine tools, *e.g.*, lathe with properly placed controls and displays.

Q. 5.20. With suitable examples, explain the various ergonomic aspects to be considered in design.

Ans. The various ergonomic aspects to be considered in design are clear when the way in which a designer perceives a human operator is considered in man-machine system.

The designer perceives man as :

(*i*) Reader of display;

(*ii*) Occupant of space;

(*iii*) Decision maker or watching a display;

(*iv*) Operator of controls to alter the speed or state of machine.

Thus Ergonomics should :

— focus on easily readable displays on machines;

— provide comfortable sitting place for operator to satisfy anthropomeric requirements.

— have controls which can be operated by human being with least effort.

Ergonomically designed automobiles, machine tools and other equipment focus on the above principles.

Q. 5.21. Discuss some of the 'Ergonomic factors' that influence the design of work stations for making assembly of three light components in large quantities.

Ans. ***Engonomic factors that affect design for workstations :***

In general certain principles of motion economy are followed in design of work stations; some of these are :

1. *Use of human body :*
   - The two hands should begin as well as complete their motion at the same time.
   - There should be minimum idle time.
   - Motion of arms should be in opposite directions and symmetric.
   - Hands motion should be confined to the lowest classification level.
2. *Arrangement of workplace :*
   - Tools, material and control should be located close in front of the operator.
   - Gravity chutes should be used if possible.
   - Lighting should be good.
   - A chair of suitable type and design should be provided.
3. A jig or a fixture should be used to *permit both hands to be active.*

Design of workplace for 3 light components A, B and C :

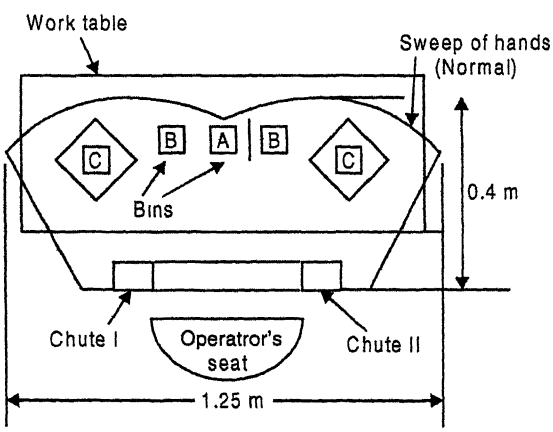


Fig. 5.8

A plan view (Fig. 5.8) shows a suitable design for bins for 3 components A, B and C to be assembled. The bins, chute and assembly board should be placed *within the normal reach of a normal operator, from the point of view of Anthropometry (Body dimensions).*

Q. 5.22. Explain briefly the applications of 'Ergonomics' in the product design.

Ans. The applications of 'Ergonomics' in the product design are as under :

1. ***Working environment.*** This group includes conditions of noise, heating and lighting etc., under which the work is to be carried out.

2. ***Instruments and controls.*** This group includes the design of the instruments which the operator must look at or listen to (called DISPLAY), and the parts of the machine or equipment on which he exerts muscular force so as to change the state of the process or operation (called the CONTROL).

3. ***Instrument design.*** An instrument provides information, and the information should be displayed to the operator in the simplest possible manner. For *example*, a car temperature gauge needs only display 'N' for normal temperature as against a fully calibrated scale which requires a motorist to know what is normal working temperature for the engine.

- *'Digital'* indicators show the required information directly as a number. A kilometer in a car is an example, where the number of kilometers covered can be read directly off the meter as a number. The advantage here is that the precise reading to the desired accuracy can be read directly from meter; however, *for a quick approximate reading at a glance, the "analogue version" gives the best results.*

— The above two types may be combined when a rate indication is required, for example (which might possibly be returned to zero), *speed in addition to a cummulative quantity.*

4. ***Multi-instrument display.*** In this case of a display having many instruments, a *logical order pattern of dials and pointer should be presented to the user.* The pointers should be set so that *they are in the same position for the 'Normal' reading of each instrument.*

- The *classic example* of this principle is provided in the ergonomic design of the instrument display in the *cockpit of a modern airliner.*

5. ***Machines and controls :***

- Levers, knobs, handwheels etc., should be positioned so that the operator can manipulate them with the least change in body position and with the greatest mechanical advantage.
- A machine for general use should be designed to suit the average human being, and statistics are available to help to do this.

Q. 5.23. Discuss briefly the classification of Man-machine system.

Ans. The man-machine system may be classified on the following basis :

1. ***Nature of man's involvement in the system :***

(*i*) *A closed-loop system :*

— It requires continuous control and feedback to function successfully (*e.g.*, a man flying a fighter plane).

— Feedback is essential in order to correct errors, if any, through continuous control.

(*ii*) *An open-loop system :*

— This type of system is one which once initiated or started needs no further control by man or at least cannot be further controlled (*e.g.*, firing a bullet from a revolver, the path of the bullet cannnot be continuously be controlled.

2. ***Degree of man versus machine control :***

(*i*) *A mannual system :*

— It is essentially a man-directed system (*e g.*, a worker cutting a mild steel bar using (hand) back saw.

— A large variability is possible in a manual system as every worker may select a different method or motions to do the same job.

(*ii*) *A semi-automatic (mechanical) system :*

— A mechanical system is more complex and inflexible in nature than a manual system, because it has components which are well integrated. The machine component is power driven and human activity is information processing, decision making and controlling.

Examples. A driver driving a car.

(*iii*) *An automatic system :*

— This system is a still more complex system in which all operational functions are performed by automatic devices. Operational functions are sensing, information processing and decision making and action. The man does the task of monitoring, programming the function, maintenance and upkeep.

Example. An automatic telephone exchange.

Q. 5.24. What are the characteristics of a Man-Machine System?

Ans. Following are the *characteristics of a man-machine system :*

1. It consists of the *man,* the *machine* and the *environment.*
2. This system is artificial and is specifically developed to fulfill the specific purpose.
3. It has specific inputs and outputs which are appropriately balanced.
4. It is variable in size and capacity and is dynamic in performance.
5. Subsystems of man-machine system interact and affect each other.
6. It becomes more efficient when output results are fed-back to the system.
7. The performance of the system is influenced by the environmental factors.

Q. 5.25. Name the different methods adopted to prevent the human errors in view of the ergonomics considerations.

Ans. *Human errors.* It has been observed that most of the equipment failure takes place mainly due to human failures or errors. Thus, we see that the overall reliability of a system is adversely affected as humans have some probability of performing tasks incorrectly.

The main *reasons* of human errors are as under :

(*i*) Poor equipment design.

(*ii*) Improper tools.

(*iii*) Inadequate training or skill.

(*iv*) Tendency to do a thing in diverse ways.

(*v*) Inadequate lighting.

(*vi*) Dusty and warm environment.

(*vii*) High noise.

(*viii*) Inadequate work layout.
(*ix*) Crowded work space.
(*x*) Poor motivation.
(*xi*) Poor understanding of operation and maintenance.
(*xii*) Lack of communication.
(*xiii*) Complex task.
(*xiv*) Poor management.

Methods for preventing human errors. The methods for preventing human errors are :

1. Man-machine systems analysis method.
2. Error-cause removal program.

1. *Main-machine system analysis method.* Under this method the following step are to be followed :

(*i*) Define the function and goals of the system in unambiguous terms.
(*ii*) Improve the environment of operator.
(*iii*) Impart proper training.
(*iv*) Provide motivation.
(*v*) Evaluate the skills of job type of experience called for.
(*vi*) Clearly state the tasks and job to be performed.
(*vii*) Determine estimate for occurrence of each potential error.
(*viii*) Determine estimate for the likelihood of each potential error remaining undetected and uncorrected.
(*ix*) Determine estimate for the consequence of each undetected potential error.
(*x*) Make recommendations for change in the system.
(*xi*) Re-valuate the system after change.

2. *Error-cause removal program.*

- The basis of this method is preventive measures. It leads to job satisfaction as the workers involvement is required in this method.
- The error and error-likely situations and accident prone situation reports are submitted by the workers. Based on such reports, the remedial or prevention measures are immediately taken up.

Q. 5.26. Discuss the various types of 'standards'.

Ans. The various types of 'standards' are discussed briefly as under :

1. *Product standards :*

- These standards establish ingredients, physical characteristics, quality and performance of a particular product.
- These are essentially technical descriptions and are made known to the buyer.
- These generally help the consumer by assuring him uniformity in quality and performance

2. *Engineering standards :*

- These standards are concerned with the parts that make up the product.
- A company making several similar products may standardise the products and equipments that help the production.

3. ***Material standards.*** The materials that are used for production (raw materials) are standardised in quality and other physical aspects.
4. ***Quality standards.*** The economical quality to be produced is decided earlier and this assumes the standard for production.
5. ***Process standards.*** The operation method is a factory or industry is standardised to get maximum benefit of easeness and cheapness in production.
6. ***Equipment standards.*** Equipment used (*e.g.*, material handling, packing, etc.) are also standardised.
7. ***Safety standards.*** This refers to the rules and regulations formed to assure the safety of men and machines working in a factory.
8. ***Administrative standards.*** The office methods and procedures are standardised to assure the most efficient working.

HIGHLIGHTS

1. The first principle of cost reduction is the use of standard sizes.
2. *Size ranges* provide a rationalisation of design and production procedures.
3. *Reliability* is defined as the probability of a device to perform its purpose adequately for the period of time intended under the operating conditions encountered.
4. The overall reliability of a system (comprising a collection of components) depends on how the individual components with their individual failure rates are arranged.
5. Most consumer products exhibit *series* reliability. In this case : $R_{system} = R_A \times R_B \times R_C \times .... \times R_n$;
6. A system in which the components are arranged to give parallel reliability is said to be *redundant*. In this case : $R_{system} = 1 - (1 - R_A)(1 - R_B) ... (1 - R_n)$
7. Reliability can be assessed through *product testing.*
8. Taguchi methods focus on improving the design of manufacturing processes and products. These methods lead to superior performance design, known as *'Robust designs'*.
9. *Ergonomics* may be defined as a science which deals with the systematic study of the relationship and interation between man, machine and working environment.
10. *Standardisation* is a process of establishing standards or units of measure by which extent, quality, quantity, value, performance, may be compared and measured.
11. The term *'simplification'* connotes the elimination of excess sizes, varieties, styles, dimensions, process and the like, based primarily upon observation and experience.
12. *Specialisation* is the devotion of particular productive resources exclusively to the manufacture of a narrow range of products.

OBJECTIVE TYPE QUESTIONS

Fill in the Blanks or Say 'Yes' and 'No':

1. The .... of a product requires a large number of corrective steps before it is finally accepted for production.
2. Every design is an attempt to fulfill a given function with appropriate layout, component shapes and ....
3. The use of standard size is the first principles of cost reduction.
4. Size .... provide a rationalisation of design and production procedures.
5. Similarity ensures simplicity and .... of design.
6. .... is defined as the probability of a device to perform its purpose adequately for the period of time intended under the operating conditions encountered.
7. Every product that is designed, fabricated and used has a .... life.
8. A study for .... concentrates on the study of the zone of chance failures.
9. If a number of elements of a system are connected such that the failure of any one element would cause complete failure, then such elements are stated to be functionally in .... and survival of each is essential for system to survive.
10. .... reliability is justified where the increase in cost due to additional components will be compensated for, by the increased reliability obtained.
11. In parallel reliability system probability of failure or probability of unreliability of overall system is the product of unreliability of each component.
12. The .... of failure rate is called MTBF.
13. Reliability of a product is determined by ....
14. .... analysis is a technique used for system safety and reliability analysis.
15. .... can be assessed through product testing.
16. Reliability prediction is an intermittent process.
17. The .... is the mean time between successive failures of a product.
18. MTBF is the same as "operating life" or 'service life".
19. An increase in MTBF does not result in a preportional increase in reliability.
20. .... is a useful measure of reliability, but it is not correct for all applications.
21. One method to increase the reliability of a system is to increase the .... in the system.
22. Reliable systems can be produced only when the reliability is considered at the design stage itself.
23. In reliability work, the exponential distribution is rarely used.
24. .... allocation is the process of assigning reliability requirements to system parts or components to achieve the overall specified reliability of a system.
25. To evaluate reliability of system, fault tree technique is commonly used.
26. Dr .... developed the foundations of 'Robust design'.
27. Taguchi method can help improve process capability.
28. Customer's loss attributable to product performance variation is often proportional to the .... the deviation of the performance characteristic from its target value.

29. .... defined as the study of the relation between man and his occupation, equipment and environment, and particularly the application of anatomical, physiological and psychological knowledge, to the problem arising there from.
30. Ergonomics, sometimes called as .... engineering.
31. .... are the base of all mass production.
32. Specialisation never results in monotony.

ANSWERS

1. design	2. materials	3. Yes	4. ranges	5. clarity
6. Reliability	7. finite	8. reliability	9. series	10. Parallel
11. Yes	12. reciprocal	13. design	14. Fault free	15. Reliability
16. No	17. MTBF	18. No	19. Yes	20. MTBF
21. redundancy	22. Yes	23. No	24. Reliability	25. Yes
26. Taguchi	27. Yes	28. square	29. Ergonomics	30. Human
31. standards	32. No.			

THEORETICAL QUESTIONS

1. Explain briefly the check rules (According to Pohl) which apply to all embodiment designs.
2. Explain briefly the following:
   (*i*) Standard sizes.
   (*ii*) Size ranges.
3. What are the steps involved in the development of size ranges?
4. Explain the term 'Reliability'.
5. List the factors which affect reliability.
6. How high reliability can be achieved? Explain.
7. Explain briefly the 'Reliability quantifiction process'.
8. What do you understand by 'Reliability data systems'? Exaplain.
9. Discuss briefly the 'theory of reliability'.
10. What do you understand by 'Reliability of the system'? Explain.
11. Explain briefly the following :
    (*i*) Series reliability.
    (*ii*) Parallel reliability.
12. What do you understand by 'Designing for optimum reliability'? Explain.
13. What are the causes of unreliability?
14. Explain briefly the various methods used for improving reliability.
15. What do you mean by 'Reliability testing'? Explain.
16. Discuss briefly the 'Taguchi philosophy'?
17. Explain briefly the tools for 'Robust design'?
18. List the seven points which highlight the distinguishing features of Taguchi's approach, which is aimed at assuring quality.

19. Define the term 'Ergonomics'.
20. What are the application of ergonomics?
21. What do you understand by 'Human engineering in design'?
22. Discuss briefly the essentials and importance of human factors.
23. Discuss briefly 'Models and approaches in ergonomics'?
24. Discuss briefly the classification of Man-machine system.
25. What are the characteristics of a Man-machine system?
26. Name the different methods adopted to prevent the human errors in view of the ergonomics considerations.
27. Define the team 'standards'.
28. What are the objects or purposes of standards?
29. What do you mean by the term 'standardisation'?
30. State the advantages and limitations of standardisation.
31. List the applications of standardisation.
32. Define the tem 'simplification'.
33. What are the advantages of simplification?
34. What is 'specialisation'?
35. State the advantages and limitations of specialisation.
36. List the applications of specialisation.

□□□

6

Design Organisation and Communication

6.1 Organisation of design, 6.2 Design communication—General aspects—nature of communication, 6.3 Technical reports; 6.4 Oral presentations; 6.5 Working drawings, 6.6 Prototype-General aspects – types of models or prototype – dimensional prototypes – uses of prototypes, 6.7 Mockups, 6.8 Preliminary and scale models, 6.9. Mathematical models ***Questions with Answers****—Highlights—Objective Type Questions–Theoretical Questions*

6.1. ORGANISATION OF DESIGN

An engineer's jobs is to organise, improve, and transmit information. The information is usually transmitted in the form of :

(*i*) Drawing;
(*ii*) Specifications;
(*iii*) Performance predictions;
(*iv*) Bill of materials required;
(*v*) Technical advice.

- An engineering office, which is well equipped, must have provision for keeping catalogues, reports, files, data books and operating manuals.

— A designer should be able to gather any information as and when required. He should set his goal clearly before him. No sooner the goal is set, variety of description is given to a problem solving process. The *description* (defined as a record of various ideas in an exhaustive manner) serves as powerful tool in the hands of a designer for good and appropriate design work.

6.2. DESIGN COMMUNICATION

6.2.1. General Aspects

Communication *is the flow of intelligence from one mind to another.*

— Communication occurs through a common system of *symbols, signs,* and *behaviour* that utilize one or more of five human senses. We communicate by acual physical touch, as in a

handshake or a pat on the back. We also communicate by visual movements of the body as with the wink of an eye or a smile. Sometimes we even communicate via taste and smell.

— In most *technical communication*, symbols or signs that are either heard with ear or seen with eyes are used.

6.2.2. Nature of Communication

Fig. 6.1 shows the basic elements of all communication activities.

— The *sources* of communication arises somewhere in the organisation. Someone has information to communicate to someone else.

— An *encoding* process occurs when the information is translated with a systematic set of symbols (language), that expresses what the source wishes to transmit.

— The product of *encoding* is the *message*. The form of message depends on the nature of communication *channel*. The channel is the modium through which the message will be carried from source to receiver. The message can be written report; a face-to-face communication, telephone call, or a transmission via a computer network. It may or may not undergo a transformation in the decoder. When it reaches the *receiver*, it is interpreted in light of the person's previous experience or frame of reference.

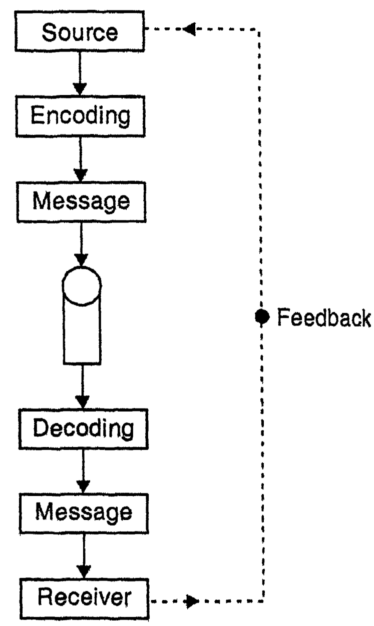


Fig. 6.1. Basic elements of communciation system.

- A communication system is *less than perfect*. Strong electric currents or atmospheric disturbance will produce some error in the transmission. These disturbances are called *noise*.

— For communication to occur, the sender must have the authority of knowledge and a purpose of generating and transmitting the message.

— Communication in an organisation is a multi-dimensional process. Many managers attempt to communicate only with the people under them and forget to communicate laterally with those who are assisting them.

6.3. TECHNICAL REPORTS

The quality of a report generally provides an image in the reader's mind that, in large measure, determines the reader's impression of the quality of the work. Of course, an excellent job of report writing cannot disguise a sloppy investigation, but many excellent design studies have not received proper attention and credit, because the work was reported in careless manner. One should be aware that written reports carry a message farther than the spoken word and have geater permenance.

Organisation of reports. The written communications take the form of letters, brief memorandum reports, formal technical reports, technical papers, and proposals.

— In terms of the communications model, the *source* is the mind of the writer. The process of encoding consists of translating the idea from the mind to words on a paper. The *channel* is the file of manuscript papers. *Decoding* the message depends on reader's ability to understand the language and familiarity with ideas presented in the message. The final *receiver* is the mind of reader. Noise is present in the form of poor writing mechanics, incomplete diagrams, incorrect references etc. Since there is no direct feedback, the writer must anticipate the needs of the receiver and attempt to minimise the noise.
— The first principle of written communication is to know your audience, so that you can anticipate and fulfill its needs.
— The information should be easy to find.

Memorandum reports. Normally the memorandum report is written to a specific person or group of persons concerning a specific topic, with which both the writer and recipient are familiar. It is writtern in memorandum form :

- Date :
- To :
- From :
- Subject :
- Introduction :
- Discussion :
- Conclusions :

— The purpose in writing a memorandum report is to get a concise report to interested parties as quickly as possible.

— The *main emphasis is on results, discussion, and conclusions* with a minimum of writing about experimental details unless, of course, those details are critical to the analysis of the data.

Formal technical reports. *A formal technical report is usually written at the end of a project*. Generally, it is a complete, stand-alone document aimed at persons having widely diverse backgrounds. Therefore much more detail is required. The outline of a typical formal report might be :

- Covering letter
- Summary
- Introduction
- Experimental procedure
- Discussion
- Conclusions
- References
- Appendices
- Tables
- Figures.

6.4. ORAL PRESENTATIONS

- Impressions and reputations (favourable or unfavourable) are made most quickly by audience reaction to an oral presentation. *Progress reports* are common situations in which oral communication is used.
- Oral communication has several characteristics :

— Quick feedback by questions and dialogue;

— Impact of personal enthusiasm;
— Impact of visual aids;
— Important influence of tone, emphasis, and gesture.

- The preparation and delivery of the speaker, the environment of the meeting room, and quality of the visual aids all contribute to the efficiency of the oral communication process.

Business-oriented technical talk. The most appropriate type of delivery for more business-oriented talks is an *extemporaneous prepared talk.* All the points in the talk are thought out and planned in detail. However, the delivery is based on a written outline, or alternatively, the next of the talk is completely written but the talk is delivered from an outline prepared from the text. This type of presentation establishes a more natural, closer contact with the audience, that is much more believable than if the talk is read by the speaker.

— Visual aids are an important part of any technical presentation. The type of visual aid to use depends upon the nature of the talk and the audience.
— The usual reason a technical talk is poor, is lack of preparation.
— The *dry run* is a dress rehearsal before a small audience. If possible, hold the dry run in the same room where you will give the talk.
— Whenever possible, avoid talking in the dark. Maintaining eye contact with the audience is an important part of the feedback in the communication loop.
— Never appologise for inadequacy of your results.

Technical society talk. The main body of the technical talk covers the following items :

(*i*) Experimental or analytical procedure.
(*ii*) Results and observations.
(*iii*) Discussions and conclusions.
(*iv*) On going research and/on future studies.

The talk should end with a summary that repeats the main information given in the body of the talk.

Visual aids and graphics. The chief purpose of a visual aid is to improve and simplify communication. There should be no intention to have a slide or view graph stand alone, unsupported by oral communication. The spoken word should complement the limited information, that can be contained on the visual. The visual aids and graphics include the following :

- Flip charts;
- Slides;
- Overhead transparencies;
- Graphics for reports.

6.5. WORKING DRAWINGS

A drawing made to provide the information necessary for doing work of any kind is called a **working drawing**.

Working drawings may be broadly *classified* as follows :

1. Detail drawing.

2. Assembly drawing.
3. Assembly working drawings.

1. Detail drawing. The *detail drawing gives the complete information for manufacture of each of the separate part On the detail drawing all components are fully dimensioned. The tolerances, surface finish, and heat treatment are indicated and necessary shop operations are given.*

— All components on the detail drawing are numbered.

— *A bill of materials* is given in the tabular form.

— Additional information, such as stock size, pattern number, standard specification number if the item is a standard one like bolts, nuts, etc., is sometimes listed.

- The detail drawing may also contain essential descriptive notes on important parts and their relationship to other parts.
- A detail drawing *should be a complete unit for the purpose intended* and should not be dependent in any way upon any other detail drawing.

2. Assembly drawing. The *assembly drawing shows the different parts in their relative positions.*

— There are many kinds of assembly drawings made for different purposes, ranging from preliminary design and layout, general assembly, erection and installation assembly, display drawing etc.

— The assembly drawing may contain the standard parts, which are not shown in detail drawing. The assembly and details may be drawn on the same sheet, if the size of the paper is large.

3. Assembly working drawing. When only a few machines are to be made for when the assembly contains only a few parts, an assembly drawing may have complete dimensions and notes, so that no separate detail drawings are required.

Part or check assembly drawings are sometimes made to show a group of parts in their proper relation to each other and either partly or completely dimensioned for use as working drawing.

6.5. PROTOTYPE

6.6.1. General Aspects

Prototype *is defined as an approximation of the product along one or more dimensions of interest.* Any entity that exhibits some aspects of the product that is of interest to the development team, can be viewed as a 'Prototype'. This definition is quite broad and includes 'Prototype' ranging from concept sketches to fully functional artifacts. So we can say that ***prototyping is a process of developing such an approximation of the product.***

- A prototype is the most expensive form of model that can be constructed for experimental purposes. Such a *prototype is a full size working model of a physical system that has been built in accordance with final specifications, it represents the final step of the experimental stage.*

— From a prototype the designers can gain information needed for mass-production procedures, that are to come later. Much can be learned at this point about workability, durability, production techniques, assembly procedures, and, most important of all, *performance under actual operating conditions.*

— Since prototype testing offers the last chance for the modification of the design, possible changes to improve the design should not be overlooked, nor should a designer ever be reluctant to make a desirable change.

- *In the development of a design, designers deal first with the mockup; next they work out specific problems relating to single features with preliminary models; then they evalute the design with scale model, and, finally, they may, if desirable test the whole concept using a prototype.* This order in the use of models maintains a desirable relationship between concept and analysis and *represents a logical procedure for the total design process.*

6.6.2. Types of Models Or Prototype

1. Ionic models :

— These models represent things as they appear, and so *sketches and drawings of all types fall under this category.*

2. Analogic models :

— These models represent specific features of the design by using an *analogy. Schematic diagrams and flow diagrams are of this type, as are circuit diagrams.*

— Analogic models can also be used to visualise properties that are abstract in nature such as bending moment and shear force.

3. Symbolic models :

— These models, *describe some aspects of product by using words, numbers or mathematical symbols.* A list of parts, *bill of materials* falls into this category.

- *'Computer models'* are based on complex algorithms made up of many mathematical equations and therefore are also *symbolic form of models.* However, it must be noted here that in this case the symbolic model lies in the *software only and can be used to create ionic and analogic models on computer screen.* A symbolic model is also important because it leads to quantitative results.

6.6.3. Dimentional Prototypes

Prototypes can be *classified* along *two dimensions.*

I. The *'first-dimension'* is the degree to which a prototype is ***physical*** as opposed to ***analytical.***

- **Physical prototypes** are *tangible artifacts created to approximate the product.* Aspects of the product of interest to the development team are actually built for testing and experimentation.

Examples :

(*i*) Models which look and feel like the product;

(*ii*) Proof-of-concept prototypes used to test an idea quickly;

(*iii*) Experimental hardware used to validate the functionality of a product.

- **Analytical prototypes** *represent the product in a no-tangible, usually mathematical manner.* Interesting aspects of the product are *analysed, rather than built.*

Examples :

(*i*) Computer simultations.

(*ii*) Systems of equations encoded within a spread sheet.
(*iii*) Computer models of three-dimensional geometry.

II. The *'second dimension'* is the degree to which a prototype is ***comprehensive*** as opposed to ***focused.***

- ***Comprehensive prototypes*** *implement most, if not all, of attributes of a product.* A comprehensive prototype corresponds closely to the everyday use of the word *prototype*, in that, it is a full-scale, fully operational version of the product.

Example : Beta prototype given to customers in order to identify any remaining design flaws before committing to production.

- ***Focused prototypes*** *implement one or a few of the attributes of a product.*

Examples :

(*i*) Foam models to explore the form of a product.
(*ii*) Wire-wrapped circuit boards to investigate the electronic performance of a product design.

— A common practice is to use two or more focused prototypes together to investigate the overall performance of a product.

6.6.4. Uses of Prototypes

Prototypes are used for the following *purposes*:

1. Learning
2. Communication
3. Integration
4. Milestones.

1. Learning. Prototypes are often used to answer two types of questions:

(*i*) Will it work?
(*ii*) How well does it meet the customer needs?

When used to answer such questions, prototypes *serve as learning tools.*

2. Communication. Prototypes enrich communication with :

— top management;
— vendors;
— partners;
— extended team members;
— customers;
— sources of financing.

This is particularly true of physical properties; a visual, tactile, three-dimensional representation of a product is much easier to understand than a verbal description or even sketch of the product.

3. Integration :

- Comprehensive *physical prototypes* are *most effective as integration tools in product development projects,* because they require the assembly and physical interconnection of all of the parts and sub-assemblies that make up a product. In doing so, the prototype forces coordination between different members of the product development team. If the combination of any of the components of the product interfers with the overall function of the product, the problem may only be detected through physical integration in a comprehensive type.

Common names for these comprehensive physical prototypes are :

— Experimental;
— Alpha;
— Beta;
— Preproduction prototypes.

4. Milestones. Milestones prototypes *provide tangible goals, demonstrate progress, serve to enforce the schedule.* Senior management often requires a prototype that demonstrates certain functions before they will allow the project to proceed.

6.7. MOCKUPS

A **mockup** *is a full-size 'dummy' constructed primarily to show the size, shape, component relationships, and styling of the finished design.* At this point, the designer can see his conception begin to take shape for the first time.

A mockup is more meaningful than a sketch, to those whose support and approval is needed. One must realise, however, that numerous sketches and artistic renderings are made before any work is started on a mockup These sketches are used as guides.

Mockups may be made of clay, wood, plastic, and so forth.

- "*Automobile manufacturers*" customarily produce mockups to evaluate proposed changes in the styling of automobile bodies for new models. Needed modification in size and body configuration can be determined by studying the mockup and analyzing its overall appearance. Since interior styling is also important, *interiors are modelled in clay to reveal the aesthetic appearance,* the stylist had in mind.

— In the automobile industry, mockups are made to secure early approval of management for model change.

6.8. PRELIMINARY AND SCALE MODELS

— In the design stage, models may be made at almost any stage to assist the designer in evaluating and analysing his design.

— *Models are made to strengthen three dimensional visualisation, to check the motion and clearance of parts, and to make necessary tests* to clear up questions that have arisen in the designer's own mind or in the mind of a colleague. The designer may prepare a preliminary model to understand more fully what the shape of a component should be, how will it may be expected to operate, and how it might be fabricated most economically.

— In some cases, the model might be so simple that it could be made of paper, wood, or clay.

— *Scale and test models* may be constructed either for analysis and evaluation or for the purpose of presenting for approval of this design, as developed in a more or less refined stage. Scale models may be made of balsa wood, plastic, aluminium, steel, or any other material that can be used to a good advantage.

6.9. MATHEMATICAL MODELS

A **model** *is a simplified representation of reality.* It is usually simplified because rreality is too complex to copy exactly and because much of the complexity is actually irrelevant to the specific problem.

Models may be *classified* as follows :

1. Iconic models.
2. Analog models.
3. Mathematical models.

1. Iconic model. It is a physical replica of a system usually *based on different 'scale' than the original.* These may appear in three dimensions such as airplane, car or bridge model to scale. Photographs are another type of iconic model but in two dimensions.

2. Analog model. It does not look like the real system but behaves like it. These are usually two dimensional charts or diagrams, *e.g.*, organisation charts showing structure, authority and responsibility relationship.

— Analog models are more abstract than iconic ones.

3. Mathematical models :

— When the concept of a model is extended to the area of *mathematics*, it is useful to know in a quantitative sense how important or how pertinent the variables are in the model with regard to their impact on the solution.

— The *mathematical models* depict explicit relationship and interrelationships among the variables and other factors deemed important in solving problems.

The structure of mathematical models. These models are typically in the form of equations or other mathematical statements. For example, the relationship between cost, revenue and profit can be expessed as :

$P = R - C$

Where, P, R and C symbolize profit, revenues and cost respectively.

In general, a distinction is made between independent (cause) and dependent (effect) variables.

Characteristics :

In order that a mathematic model may be used successfully in typical Management Science (MS) project, it must meet the following criteria; the model should be :

- simple and understandable;
- reasonable;
- easy to maintain and control;
- adaptive;
- complete on important issues.

Advantages :

1. Use of models *avoid* constructing costly plants and warehouses in locations that do not best meet the present and future needs of the customers.
2. A model indicates *gaps* that are not immediately apparent, and after testing, the character of the failure might give a clue to the model's deficiencies.
3. Models have the advantage of time, since results can be obtained within a relatively short time.
4. Because of the constant seqeeze on profits, the *cost* and *time* saving that MS models allow, make them decision making tools of great value to the manager.

Disadvantages :

1. A model that simplifies may inaccurately reflect the real work situation.
2. If a peson who builds a model does not know what he has done, output from the model will be incorrect.
3. Models can sometimes prove too expensive to originate, when their cost is compared to the expected return from their use.

QUESTIONS WITH ANSWERS

Q. 6.1. What do you mean by 'Modelling and simulation'?

Ans. A **model** *is an idealisation of reality.* Once a model is developed and experimentation on the model is carried out, it is possible to understand the real world problem.

Experimentation and manipulation with the model is called **Simulation.**

Q. 6.2. Explain briefy the modelling process in design.

Ans. For a designer to predict the future characteristics of a product it must be possible to simulate its behaviour. For achieving this he has to examine specific aspects of the design and by modelling these aspects final artefact can be predicted. *'Modelling process' is an essential element of the design process because through models a designer is able to establish and know how the design will be built and to evaluate how it will perform*

Models can be presented in many forms, one of them is a set of drawings. A designer can present the final product of a model by use of drawings. But *drawings are only one type of model.* Other types of models are :

(*i*) Ionic models;
(*ii*) Analogic models;
(*iii*) Symbolic models.

Models perform the following functions :

(*i*) To evaluate a design by simulating certain aspects of its performance.
(*ii*) To assist in the earlist stages of design, when the problem is being defined and solution concepts are generated.
(*iii*) To communicate the required information between interested parties, such as designer, client, manufacturer and operator.

HIGHLIGHTS

1. *Communication* is the flow of intelligence from one mind to another.
2. A *formal technical report* is usually written at the end of a project.
3. Pregress reports are common situations in which oral communication is used.
4. The *dry run* is a dress rehearsal before a small audience.
5. The *detail drawing* gives the complete information for manufacture of each of the separate parts.
6. The *assembly drawing* shows the different parts in their relative positions.

7. Prototype is defined as an approximation of the product along one or more dimensions of interest.
8. *Various* types of models are : (*i*) Ionic models; (*ii*) Analogic models; (*iii*) Symbolic models.
9. A *mockup* is a full-size dummy constructed primarily to show the size, shape, component relationships, and styling of the finished design.

OBJECTIVE TYPE QUESTIONS

1. The .... is defined as a record of various ideas in an exhaustive manner.
2. .... is the flow of intelligence from one mind to another.
3. Communication occurs through a common system of symbols, signs and .... that utilise one or more senses.
4. A communication system is less than perfect.
5. .... in an organisation is a multi-dimensional process.
6. In terms of the communications, the .... is the mind of the writer.
7. The information should be .... to find.
8. A formal technical report is usually written in the beginning of a project.
9. The usual reason a technical report is poor, is lack of preparation.
10. The chief purpose of a visual aid is to .... and simplify communication.
11. A drawing made to provide the information necessary for doing work of any kind is called a .... drawing.
12. The .... drawing gives the complete information for manufacture of each of the separate parts.
13. The .... drawing shows the different parts in their relative positions.
14. .... is defined as an approximation of the product along one or more dimensions of interest.
15. .... models, represent things as they appear.
16. Analogic models represent specific features of the design by using an ....
17. .... models describe some aspects of the product by using words, numbers or mathematical symbols.
18. Physical prototypes are tangible artifacts created to approximate the product.
19. .... prototypes represent the product in a non-tangible, usually mathematical manner.
20. A .... is a full-size dummy constructed primarily to show the size, shape, component relationships, and styling of the finished design.

ANSWERS

1. description	2. Communication	3. behaviour	4. Yes	5. Communication
6. source	7. easy	8. No	9. Yes	10. improve
11. working	12. detail	13. assembly	14. Prototype	15. Ionic
16. analogy	17. symbolic	18. Yes	19. Analytical	20. mockup.

THEORETICAL QUESTIONS

1. What do you understand by 'Organisation of design'?
2. What do you mean by the term 'Communication'?
3. Explain briefly the basic elements of communication system.
4. Explain briefly the following :
   (*i*) Technical reports.
   (*ii*) Organisation of reports.
   (*iii*) Memorandum reports.
5. What do you mean by 'Oral presentation'? Explain.
6. List the characteristics of oral communication.
7. Discuss briefly the following :
   (*i*) Business-oriented technical talk.
   (*ii*) Technical society talk.
   (*iii*) Visual aids and graphics.
8. What do you understand by 'Working drawing'.
9. Explain briefly the following :
   (*i*) Detail drawing.
   (*ii*) Assembly drawing.
   (*iii*) Assembly working drawing.
10. Define the term 'Prototype'?
11. Explain briefly the various types of models.
12. Discuss briefly the following :
    (*i*) Physical prototypes
    (*ii*) Analytical prototypes.
13. Explain briefly the uses of prototypes.
14. Write a short note on 'Mockups'.
15. Discuss briefly the following :
    (*i*) Preliminary and scale models.
    (*ii*) Mathematical models.
16. What are the characteristics, advantages and disadvantages of mathematical models.

□□□

7

Concept of Manufacturing

7.1. INTRODUCTION

In general, **manufacturing** *is the economic term for making goods and services available to satisfy human wants.* In fact manufacturing involves a series of related activities and operations such as :

(*i*) Product design and development;
(*ii*) Material selection;
(*iii*) Process planning;
(*iv*) Inventory control;
(*v*) Quality assurance;
(*vi*) Marketing etc.

In view of the above activities and operations, manufacturing is no longer a simple operation but has become a *system* where a number of sub-systems interact in a dynamic manner.

7.2. MANUFACTURING SYSTEM

7.2.1. General Aspects

- *Any system that produces useful products or services, in general, is called a* **Production system.**
- **Production** *may be considered as a process of transformation of a set of input elements whereby the utility of goods or services increased.* For example, the input could be parts and the assembled product serves as output.

- *The manufacturing processes are collected together to form a* **manufacturing system.** The manufacturing system takes inputs and produces products for the customer.

A manufacturing system is depicted as an input-output system, in Fig. 7.1. Here the input elements undergo technological transformation to yield a set of output elements. The technological transformation must be optimised with reference to an objective function which could be cost, productivity or product.

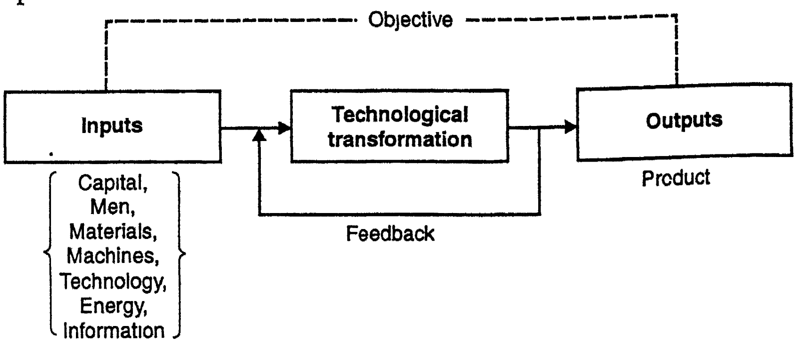


Fig. 7.1. Manufacturing as an input-output system.

— *"Manufacturing" is the heart of the system where material is converted from one form to another and value is added.*

— *The "manufacturing sub-system"* is a collection of processes and operations that are used to obtain the desired product in the required quantity.

- The present day concept of 'manufacturing system' has evolved through the following *five distinct stages :*
  1. Manual manufacturing.
  2. Mechanisation.
  3. Hard automation.
  4. Soft automation
     — NC/CNC/DNC
     — Industrial robots
     — FMC (Flexible Manufacturing Cell)/FMS (Flexible Manufacturing System)

  The major components of the FMS are : *(i) Machine tools; (ii) Control system; (iii) Handling system; (iv) Operators.*

  — Computer Aided Design (CAD)/Computer Aided Manufacturing (CAM).

7.2.2. Classification of Manufacturing Processes

The principal types of manufacturing are :

1. Process-type manufacturing. It involves *continuous flow of materials through a series of process steps to obtain a finished product like chemicals.*

2. Fabrication-type manufacturing. It involves *manufacturing of individual parts or components* by a series of operations, such as rolling, machining and welding.

Here, the following basic manufacturing processes are used :

Casting; Forming; Machining; Guiding and Finishing; Unconventional Machining; Joining; Heat treatment.

3. Assembly-type manufacturing. In this type of manufacturing the *parts or components are put together to get a complete product* such as a machine.

The manufacturing processes are ***classified*** *as follows :*

I. Constant mass processes :

1. *Casting :*
   - (*i*) Sand casting
   - (*ii*) Shell mould casting
   - (*iii*) Precision investment casting
   - (*iv*) Plaster mould casting
   - (*v*) Permanent mould casting
   - (*vi*) Die casting
   - (*vii*) Centrifugal casting.
2. *Metal forming processes :*
   - (*i*) Rolling
   - (*ii*) Drop forging
   - (*iii*) Press forging
   - (*iv*) Upset forging
   - (*v*) Extrusion
   - (*vi*) Wire drawing
   - (*vii*) Sheet metal operations
3. *Powder metallurgy processing.*
4. *Heat treatment.*

II. Metal removing processes :

1. *Machining :*
   - (*i*) Turning
   - (*ii*) Drilling
   - (*iii*) Milling
   - (*iv*) Shaping and planning
   - (*v*) Sawing
   - (*vi*) Broaching.
2. *Grinding and finishing.*
3. *Unconventional machining.*

III. Material addition processes :

1. *Welding and allied processes :*
   - (*i*) Gas welding
   - (*ii*) Electric arc welding
   - (*iii*) Electric resistance welding
   - (*iv*) Thermit welding
   - (*v*) Cold welding

(*vi*) Brazing
(*vii*) Soldering.

2. *Mechanical joining :*
(*i*) Bolting
(*ii*) Riveting etc.

7.2.3. Selection of a Manufacturing Process

- In order to produce the product with least cost within reasonable time without compromising the quality of the product, it is imperative to *select the right type of manufacturing process.*
- The final product should satisfy both functional and physical objectives at a minimum cost that is acceptable to the ultimate user. For this purpose *production and process-product topology technique is used.*

For *selecting a manufacturing process,* the following points should be given due consideration :

(*i*) Manufacturing cost.
(*ii*) Production volume and production rate.
(*iii*) Characteristics and properties of workpiece material.
(*iv*) Limitations on shape and size.
(*v*) Surface finish and tolerance requirements.
(*vi*) Functional requirements of the product.

7.2.4. Process Planning

- Process planning aims at planning method or series of methods for economic manufacturing of a product of the quality called for by the drawings or specifications laid down.
- It is a fundamental part of the industrial activity. An efficient and economic planning leads the firm towards success whereas faulty planning creates hindrances and bottlenecks at each stage of manufacturing.

Following are the *purposes of process planning :*

(*i*) To determine the most economical process to be followed to manufacture components of the product which are to be manufactured in the shops.
(*ii*) To determine what parts to be manufactured and what parts to be purchased from the market.
(*iii*) To determine the sequence of operations to be performed on each component in particular process.
(*iv*) To determine the blank sizes of raw materials in processes like forging, welding, processing and gross weight of material, for casting purpose.
(*v*) To prepare a list of materials for all components of the product in preparation to purchasing the raw materials.
(*vi*) To determine the machine tools to do the operations at required accuracies and prepare complete specifications of such machine tools.

(*vii*) To determine the need of any special equipment like tools, figs and fixtures and dies in the light of production quantities.

(*viii*) To determine the stages of inspection and also, the need of designing the inspection devices and limit gauges for different stages of manufacturing.

(*ix*) To determine the time standards for performance of the job and fix the rates of payments in piece payment system.

(*x*) To determine the type of labour required to do the job and the estimated product cost prior to the start of manufacturing.

7.2.5. Analysis of Manufacturing System

Methods employed for manufacturing system analysis are enumerated and briefly discussed as follows :

1. Linear programming.
2. Waiting line model.
3. Simulation models.
4. Network models.
5. Statistical techniques.

1. Linear programming :

- This method has emerged from the combination of mathematics and economics and is an improved method of doing the job.
- It provides a general model to obtain the most economic way of allocating the scarce resources.
- It deals equally well when a group of limited resources must be shared amongst a number of competing demands and all decisions are interlinked because of the common set of fixed limits. Fixed limits are set by machine tool capacity, plant capacity, raw materials storage space etc.

  Simplex method, graphical method etc. may be used to solve such distribution problems.

2. Waiting line model :

- This method involves the arrival of units which require service at one or more service facilities; under situation, units may have to wait for certain period.
- *Waiting is always associated with costs.* Hence the problem is to organise the system in such a fashion that *waiting and costs are minimum.*

3. Simulation models :

- It has been observed that some industrial systems are very complicated and as such it is very difficult to expresses them in any mathematical form. However, the data has got some characteristics which can help to lead to simple solution of managerial problems. This approach to problems sets up a simulated experiment and then carries through the experiment completely on paper or computer to observe the effect of the variables on the measure of effectiveness.

- In general simulation models follow a conceptual structure and may not lead to optimum answer.
- It is *a good tool to compare the various alternatives.*

4. Network models. This method is commonly used to carryout the various projects where the number of operating parameters are involved and large number of decision points are there in the sequence. It is expected that the work required to be done can be easily handled with the help of network techniques.

5. Statistical techniques. In order to solve the problems, various statistical techniques can be employed such that effective decision can be approached related to manufacturing system analysis.

7.3. TYPES OF PRODUCTION

The various *types of production* are :

1. Job order production.
2. Batch or quantity production.
3. Mass production.

1. Job order production :

- It consists of *small scale production to meet the requirements of individual customers.*
- It is carried out in *small factories* and suits for various works.
- It has a lot of flexibility for operation and is capable of technical economics, but does not have commercial and financial economics.
- Continuous and careful thought must given to the development of cheaper manipulative process which involves a number of types of operations.
- The workers in the department should have skill, intelligence and very good ability.

2. Batch or quantity production :

- This is a common type of production.
- It requires very good managerial skill to achieve an economic plan in production.
- The *most economic size* is determined by sales demand, delivery and stock requirements.
- The jobs are produced in a *lot or in certain quantity* and this *varies between the job production and the mass production.*
- This can be had in a *medium size enterprise where equipment etc. cannot* be purchased in a *large scale,* but to cater say a local market and for the local demand.

3. Mass production :

- It means a continuous production without loss of time.
- It requires a good site plan, factory layout and special machinery and expensive jigs and fixtures.
- Processing and assembling are carefully timed, sometimes to a fraction of a second.
- Inspection is to be very rigid.
- The cost of machining will be very low due to less stock involved, good control of production and higher output of the machines.

- The *disadvantages* in this type of production are : *It is not easily changeable to other types of production,* costlier to change over and loss of time involved in the period of changeover etc.

7.4. CONTROL SYSTEMS

7.4.1. Introduction

Automatic control has played a significant role in the advance of engineering science. Besides its extreme importance in space-vehicle systems, missile-guidance systems, etc., *automatic control has become an important and integral part of modern manufacturing and industrial processes.* Automatic control, for example, is essential in :

— Design of auto pilot systems in *aero space industries.*
— Design of cars and trucks in the *automobile industries.*
— *Industrial operations as controlling pressure, temperature, humidity, viscosity and flow in the process industries.*

7.4.2. System

A system may be defined as follows :

- *"A* **system** *is an arrangement, set or collection of things connected or related in such a manner as to form an entirely or whole".*

  Or

  "A **system,** *is an arrangement of physical components connected or related in such a manner as to form and/or act as an entire unit."*
- A system consists of a sequence of components in which *each component has some cause as input and its effect will be its output. Broadly it is a sequential set of cause and effects.*

Each system may have a *large number of subsystems.* Examples :

(*i*) This universe is itself a system consisting of large number of subsystems.
(*ii*) Human body as a system has digestive system, respiratory system etc.

7.4.3. Control System

A **control system** *is an arrangement of physical components connected or related in such a manner as to command, direct or regulate itself or another system.*

Elements of a control system :

The elements of a control system are enumerated and defined below :

Element	*Definition*
1. *Controlled variable*	The quantity or condition of the controlled system which can be directly measured and controlled is called *controlled variable.*
2. *Indirectly controlled variable*	The quantity or condition related to controlled variable, but cannot be directly measured is called *indirectly controlled variable.*

3. *Command*	The input which can be independently varied is called *command.*
4. *Reference input*	A standard signal used for comparison in the closed-loop system.
5. *Actuating signal*	The difference between the feedback signal and reference signal is called *actuating signal.*
6. *Disturbance*	Any signal other than the reference which affects the system performance ia called *disturbance.*
7. *System error*	The difference between the actual value and ideal value is called *system error.* The negative value is called *deviation.*

Examples of control system applications :

Following are some examples of control system applications :

1. Steering control of automobile.
2. Print wheel control system.
3. Industrial sewing machine.
4. Sun-tracking control of solar collectors.
5. Speed control system.
6. Temperature control of an electric furnace.

7.4.4. Classification of Control Systems

Control systems are *classified* into the following *two basic types :*

1. Open-loop control systems (Unmonitored or non-feedback control systems).
2. Closed-loop control systems (Monitored or feedback control systems)

Comparison between Open-loop and Closed-loop Systems

Open-loop	*Closed-loop*
1. Less accurate.	1. More accurate.
2. Generally build easily.	2. Generally complicated and costly.
3. Stability can be ensured.	3. May become unstable at times.
4. Presence of non-linearities cause malfunctioning.	4. It usually performs accurately even in the presence of non-linearities.
5. Any change in system component cannot be care of automatically.	5. Change in system component is automatically taken care of.
6. Input command is the sole factor responsible for providing the control action.	6. The control action is provided by the difference between the input command and the corresponding output.
7. The control adjustment depends upon human judgement and estimate.	7. The control adjustment depends on output and feedback element.
Examples :	***Examples :***
(*i*) Automatic washing machine.	(*i*) Liquid level control system.
(*ii*) The electric switch.	(*ii*) Traffic signal system.
(*iii*) An automatic toaster.	(*iii*) Human being reaching for an object.
Note. All control systems *operated by present timing mechanisms are open-loop.*	

7.4.5. Open-loop Control Systems (Non-feedback Systems)

- An **open-loop control system** is *one in which the control action is independent of the desired output. The actuating signal depends only on the input command and output has no control over it.*
- The **elements** of an open-loop control system can usually be *divided* into the following two parts (See. Fig. 7.2) :
  (*i*) Controller;
  (*ii*) Controlled process.

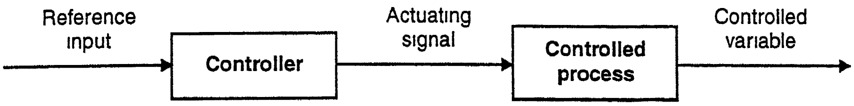


Fig. 7.2. Elements of an open-loop control system.

— An input signal or command is applied to the controller, whose output acts as the actuating signal ; the actuating signal then controls the controlled process so that the controlled variable will perform according to prescribed standards.

— In "*simple cases*", the controller can be an *amplifier, mechanical linkage, filter* or *other control element*, depending on the nature of the system. In "*more sophisticated cases*", the controller can be a computer such as a *microprocessor.*

— Because of the *simplicity and economy* of open-loop control systems we find this type of system in many *non-critical applications.*

Examples :

1. ***Idle-speed control system :***

- The following are the main *objectives* of the idle-speed control system of automobile:
  (*i*) To eliminate or minimize the speed drop when engine loading is applied.
  (*ii*) To maintain the engine idle speed at a desired value.
- Fig. 7.3 shows an idle-speed control system from the stand point of inputs-system-outputs. In this case the throttle angle and the load torque (due to the application of air conditioning, power steering, transmission, power brake, etc.) are the inputs, and the engine speed is the output. The engine is the controlled process of the system.

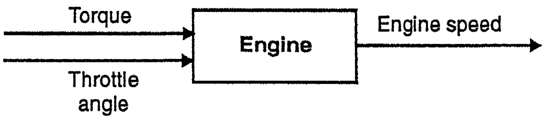


Fig. 7.3. Idle-speed control system.

2. ***Print wheel control system :***

Fig. 7.4 shows an example of the printwhecl control system of a word processor or electronic typewriter (and also shows a typical input-output set for the system).

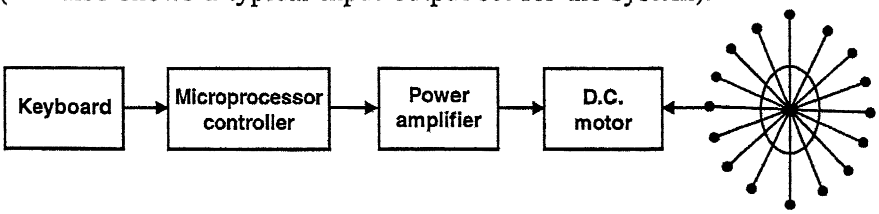


Fig. 7.4. Open-loop word processor control system.

— With a reference command input is given, the signal is represented as a step function. Since the electric windings of the motor have inductance and the mechanical load has inertia, the printwheel cannot respond to the input instantaneously. Typically it will follow the response and settle at the new position after sometime. Printing should not begin until the printwheel has come to complete stop; otherwise, the character will be smeared.

Advantages and limitations of open-loop control system :

Advantages :

1. Simple construction.
2. Easy maintenance.
3. Less costly than a closed-loop system.
4. No stability problem.
5. Convenient when output is difficult to measure or measuring the output precisely is economically not feasible.

Limitations/Disadvantages :

1. Since the system is affected by internal nnd external disturbances, the *output may differ from the desired value.*
2. For getting accurate results, this system needs frequent and careful calibrations.
3. Any change in system component cannot be taken care of automatically.
4. Presence of non-linearities cause malfunctioning.

7.4.6. Closed-loop Control System (Feedback Control System)

- A **closed-loop system** is one in which *control action is somehow dependent on the output.* In this case the controlled output is fedback through a *feedback element* and compared with the reference input. Thus the *actuating signal is the difference of desired output and reference input.*
- **Feedback** is that property of a closed-loop system which permits the output or some other controlled variable of the system, to be compared with the input to the system, so that the appropriate control action may be formed as some function of the output and input. *A feedback is said to exist in a system when a closed sequence of cause and effect relations exists between system variables.*

*The **characteristics** of feedback are as follows :*

(*i*) Increased bandwidth.
(*ii*) Increased accuracy.
(*iii*) Tendency towards oscillation or instability.
(*iv*) Reduced effects of non-linearities and distortion.
(*v*) Reduced sensitivity of the ratio of output to input to variations in system characteristics.

- A **closed-loop idle-speed control system** is shown in Fig. 7.5.

— The reference input (ω_r) sets the desired idling speed. The engine speed at idle should agree with reference value ω_r, and any difference such as load torque is

sensed by the speed transducer and the error detector. The controller will operate on the difference and provide a signal to adjust the throttle angle to correct the error.

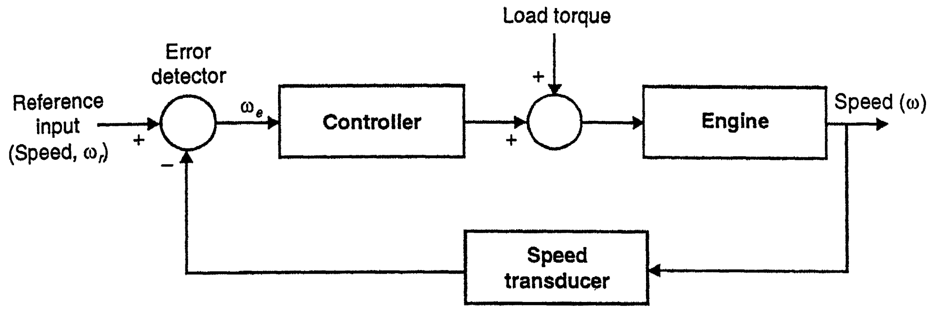


Fig. 7.5. Closed-loop idle-speed control system.

- **Advantages and Limitations :**

Advantages :

1. More accurate comparatively.
2. Usually performs accurately even in the presence of non-linearities.
3. Change in system component is automatically taken care of.
4. The use of feedback system response is relatively insensitive to external disturbances and internal variations in system parameters. It is thus *possible to use relatively inaccurate and inexpensive components to obtain the accurate control of a given plant* (whereas doing so is impossible in the open-loop case).

Limitations/Disadvantages :

1. Generally complicated in construction.
2. Generally higher in cost and power.
3. May become unstable at times.

7.4.7. Automatic Control Systems

- A closed-loop control system operating without human operator is called an *automatic control system.*

Examples :

(*i*) *Centrifugal watt governer,* where the lift of the rotating balls is used as speed monitor. The supply of steam is automatically controlled as speed tends to increase or decrease beyond a set point.

(*ii*) A *pressure control system* where the pressure inside the furnace is automatically controlled by affecting changes in the position of the damper.

(*iii*) The *level control system* where the inflow of water to the tank is dependent on the water level in the tank. The automatic controller maintains the liquid level by comparing the actual level with a desired level and correcting any error by adjusting the opening of the control valve.

Advantages and Limitations :

Advantages :

1. Increased output.
2. Economy in operating cost (since continuous employment of human operator is not required).
3. Suitability and desirability in the complex and fast acting systems which are beyond the physical abilities of a man.
4. Improvement in the quality of the products.
5. Reduced effect of non-linearities and distortions.
6. Response is satisfactory over a wide range of input frequencies.

Limitation. Automatic control system has a tendency to *overcorrect errors* which may *result in oscillations of constant or changing amplitude.*

7.5. ORGANISATION, ADMINISTRATION AND MANAGEMENT

These terms may be defined as follows :

Organisation. *It is defined as a systematic, co-ordination and combination of the efforts with the aid of the money, men, machinery, materials and methods in a manner as would result in maximum manufacturing efficiency with minimum cost.* It must embrace within itself the formulation of sound financial and commercial policy for the business, efficient planning of works building and plant equipment, judicious buying, effective conduct of productive operations, proper direction, supervision and control of personnel and a co-ordination and co-relation of the productive as also the non-productive forces into a harmonious whole.

Administration. *It is the effectuation of the purpose by means of organisation and is concerned with "Carrying out" policies, rules, regulations and designated methods.*

Management. *It is the art of creating industrial relations of any kind, between people engaged in industry viz. relations between employers and employees, relation between individuals entering into commercial contracts, relation between investors and debtors etc.*

7.6. PLANT ORGANISATION

Plant. *A plant is a place, where men, materials, money, equipment, machinery etc. are brought together for manufacturing products.*

Organisation. Organisation *is the pattern of ways in which a large number of people engaged in a complexity of tasks relate themselves to each other in systematic establishment and accomplishment of mutually agreed purposes.*

A few *common principles of organisation are :*

(*i*) Consideration of objectives
(*ii*) Relationship of basic components
(*iii*) Responsibility and authority
(*iv*) Span of control
(*v*) Dividing and grouping work
(*vi*) Effective delegation
(*vii*) Communication
(*viii*) Line and staff relationships
(*ix*) Balance, stability and flexibility.

The structure of an industrial organisation differs from that of another organisation and it depends upon :

(*i*) Size of the organisation,

(*ii*) Nature of product being manufactured, and

(*iii*) Complexity of the problem being faced.

A few commonly known forms of *organisation structures* or types of organisation are :

1. "Line" or "Departmental" type of organisation.
2. "Functional" type of organisation.
3. "Line and staff type" of organisation.
4. "Complex organisation" or "Line, functional and staff organisations".

1. **"Line" or Departmental type of organisation.** It is also called *"Scalar"* or *Military* type organisation. In this type of organisation the authority flows directly from the boss to various sub-executives in charge of particular phases of the business and from them to the other workers. Fig. 7.6. illustrates this type of organisation. It is evident from the figure that superintendent is under direct control of general manager and foreman of the departments receive orders and instructions straight way from superintendent whilst workmen are under direct authority of a formen of different departments.

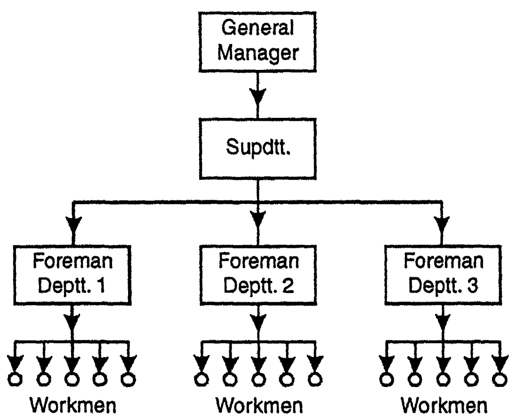


Fig. 7.6. Line organisation.

The activities of such an organisation are limited to a fewer functions such as finance, production and distribution. Each of these functions are further subdivided into self-sufficient sections which are managed and supervised by departmental heads.

Advantages :

(*i*) Simplicity
(*ii*) Flexibility
(*iii*) Quick decisions
(*iv*) Communication
(*v*) Executive development
(*vi*) Unified control
(*vii*) Fixed responsibility
(*viii*) Effective discipline
(*ix*) Economy.

Demerits :

(*i*) Overburdening
(*ii*) Instability

(*iii*) Lack of specialisation
(*iv*) Autocratic control
(*v*) Difficulty in staffing
(*vi*) Inadequate communication.

2. "Functional" type of organisation. The limited scope of working to which the *"Line"* organisation is liable has given rise to another type of organisation known as *"Functional"* type of organisation. *It divides the responsibility according to the functions to be performed and not in departments or sections of the works.* Here each individual executive is placed in full control of a function and by virtue of his total efforts being excercised in one direction, becomes a highly skilled specialist in his own field. He is thus able to look after its working with great ability, confidence and technical skill. Furthermore, this scheme presents an adequate scope for the growth and development of business, for despite its expansion even to any considerable extent; each functional head will still be able to attend to and control the activity for which he is responsible.

Figure 7.7 shows a functional type of organisation.

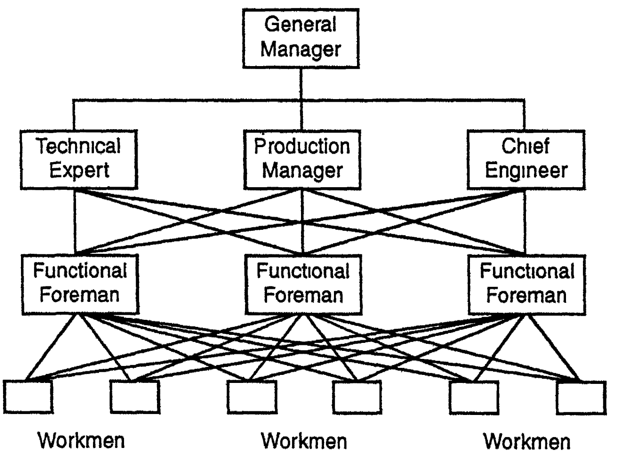


Fig. 7.7. "Functional" organisation.

Technical expert, production manager and chief engineer are under the authority of general manager. Each of the functional formen is responsible to the above mentioned departmental heads. Similarly all the workmen are to carry out the orders issued by every functional foreman.

Advantages :

(*i*) Specialisation
(*ii*) Easier staffing
(*iii*) Simplified control
(*iv*) Better supervision
(*v*) Scope for expansion
(*vi*) High efficiency.

Demerits :

(*i*) Lack of co-ordination
(*ii*) Delayed decisions
(*iii*) Poor discipline
(*iv*) Low morale
(*v*) Lack of executive development
(*vi*) Uneconomical
(*vii*) Divided responsibility.

3. Line and staff organisation. This type of organization assimilates the features of both the previously discussed types. Its main characteristic feature is that *it draws a rigid line*

between direction on one hand and the execution of work on the other. The **"Staff"** represents the directing, standardising, analysing and advising part of the efforts whilst **"Line"** *corresponds to the actual performance of the tasks.* The "staff" points out the way to efficient and economic performance and shoulders the responsibility for efficiency of equipment and quality of material, maintaining cost and analytical records, conducting time study, fixing pieces rates etc. At times, the staff work is conducted through the medium of experts with the help of committees framed for multipurposes such as Tools committee, Research committee, Production committee etc. The foreman or executive head of each department is also taken as a member of such committees and the members meet at regular intervals to discuss most economical and efficient ways of carrying out the objectives effectively. These committees are simply advisory and supplementary to the line, and in no way should supercede the management which is entrusted mainly with the duty to manage the entire affairs.

Figure 7.8 shows a line and staff organisation. Vertical line starting from General manager represents the 'line relations' while horizontal lines emanating from process and product specialists signify the 'staff relationship'.

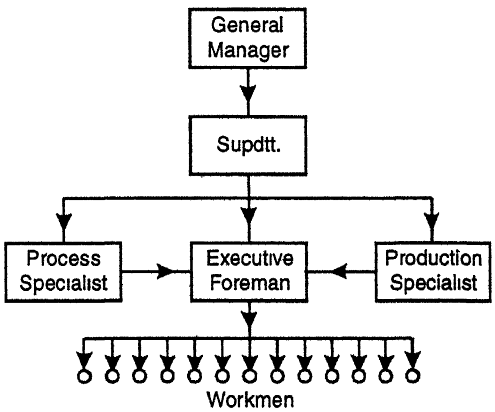


Fig. 7.8. Line and staff organisation.

Advantages :

(*i*) Discipline
(*ii*) Balanced decisions
(*iii*) Planned specialisation
(*iv*) Undivided responsibility
(*v*) Flexibility
(*vi*) Staffing and development.

Demerits :

(*i*) Ineffective staff
(*ii*) Conflicts
(*iii*) Expensive
(*iv*) Lack of co-ordination.

4. "Complex" or "Line, functional and staff" organisation. Fig. 7.9 represents the line, functional and staff relationship. It reveals that personnel manager is shown in a staff relationship to the remainder of the organisation; though not a standard arrangement yet it recognizes the way in which most personnel managers conceive their role in the organisation, as being advisory to all departments on personnel matters. Further there is a line relationship in the personal

department itself and some of the line subordinates of the personnel manager are entrusted with functional responsibility and authority.

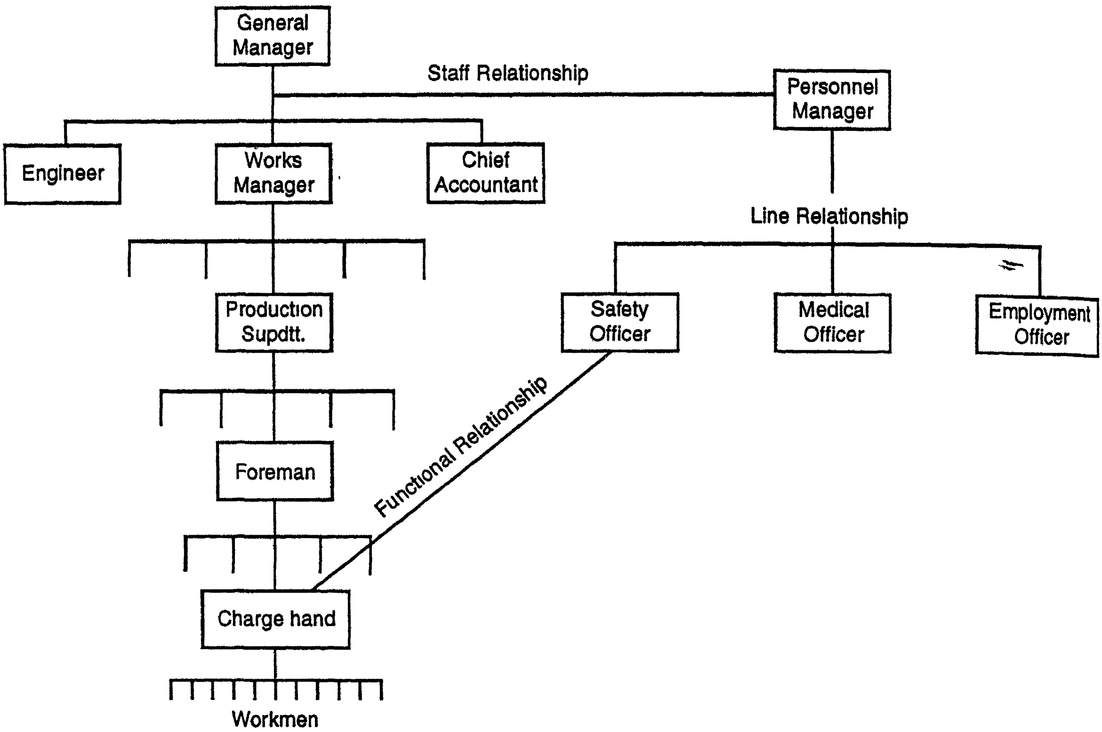


Fig. 7.9. Complex organisation.

7.7. SCIENTIFIC MANAGEMENT

7.7.1. Definition

Scientific management may be defined as a *systematic approach to manage the enterprise on the basis of observation, experimentation and rational decisions.* The methods based on guess work, trial and error should always be avoided.

7.7.2. Principles

In order to achieve the objectives of an organisation following *principles* constituting scientific management are observed :

(*i*) Scientific method of production.

(*ii*) Standardisation.

(*iii*) Time and motion study.

(*iv*) Costing and cost control.

(*v*) Production planning and control through functional foremanship.

(*vi*) Scientific selection, training and remuneration of the workers.

7.7.3. Aims

The *aims of scientific management* are :

1. Placement of right person on the right job through scientific selection and training.
2. Reduction in cost of production by rational planning and regulation of cost control techniques.
3. Increase in rate of production by use of standardised tools, equipment and methods.
4. Elimination of wastage in the use of resources, time and methods of operation.
5. Relative wage payment according to the efficiency of the worker.
6. Improvement in the quality of the products by research, quality control and inspection devices.
7. Ensuring steady flow of standard goods to customers at fixed price.

7.8. FUNCTIONS OF MANAGEMENT

Function of management can be *classified* into the following *six* activities :

(*i*) Planning (*ii*) Organising
(*iii*) Staffing (*iv*) Directing
(*v*) Controlling (*vi*) Co-ordinating.

Elements of communication. The process of communication consists of the following *components* :

(*i*) Communicator (*ii*) Message
(*iii*) Communication symbol (*iv*) Communication channel
(*v*) Receiver.

7.9. PLANT LOCATION

Some *important factors affecting plant location* are :

(*i*) Nearness to raw materials (*ii*) Transport facilities
(*iii*) Nearness to markets (*iv*) Availability of labour
(*v*) Availability of fuel and power (*vi*) Availability of water
(*vii*) Climatic conditions (*viii*) Financial and other aids
(*ix*) Land (*x*) Community attitude.

7.10. PLANT LAYOUT

A few sound *principles of plant layout are :*

(*i*) Integration (*ii*) Minimum movements and material handling
(*iii*) Smooth and continuous flow (*iv*) Cubic space utilization
(*v*) Safe and improved environment (*vi*) Flexibility.

Objectives of good layout :

Following are the important objectives of a good layout :

1. Reduce manufacturing costs.
2. Better quality of product.
3. Better service to the customer.
4. Increase flexibility.

5. Increase employee safety.
6. Reduce work-in-process to minimum.
7. Minimise materials handling and loss.
8. More effective utilization of floor space.
9. Better work methods and utilization of labour.
10. Improve control and supervision.
11. Better utilization of equipment and facilities.
12. Reduce manufacturing cycle.

Fundamental considerations in layout :

The following are among the major fundamentals most often cited :

1. Products manufactured.
2. Operations sequence.
3. Special requirements.
4. Equipment.
5. Maintenance and replacement.
6. Minimum movement.
7. Flow.
8. Waiting and service areas.
9. Plant climate.
10. Flexibility.

Types of layout. Plant layout may be classified in two fundamental types.

1. Process layout.
2. Product layout.

1. Process layout. It is sometimes also called *functional layout.* A plant is said to have process or functional layout *when all the machines of a particular class doing a particular type of work or process are arranged in a separate department.* In other words, performance of each type of work or operation in a distinct department on all types of products is the basic characteristic of process layout. Suppose 'B' has set up a factory for the manufacture of taps, reamers and drills. To manufacture these tools three principal operations naming turning, heat treatment and grinding will be involved. It may be noted that only these three different tools have common feature and there will be established three sections or departments, *viz.*, turning department, heat treatment department and a grinding department. Thus in this example all the three types of products would travel through the above mentioned principal operations without which the manufacture will not be possible.

It is evident from the above discussion that process grouping or layout creates such conditions in which *similar machines or operations are grouped functionally.* This grouping or set up is carried out in the domain of the factory known as shops or departments.

This type of layout is suitable for *job order plants which involve non-repetitive processes.*

A typical process or functional layout is shown in Fig. 7.10.

Advantages :

1. Greater specialisation.
2. Better utilization of high production equipment.
3. Greater flexibility of production process and higher degree of machine utilization.
4. Greater margin of safety of breakdowns.
5. Better supervision due to specialized process.
6. Less investments for equipments due to less duplication.

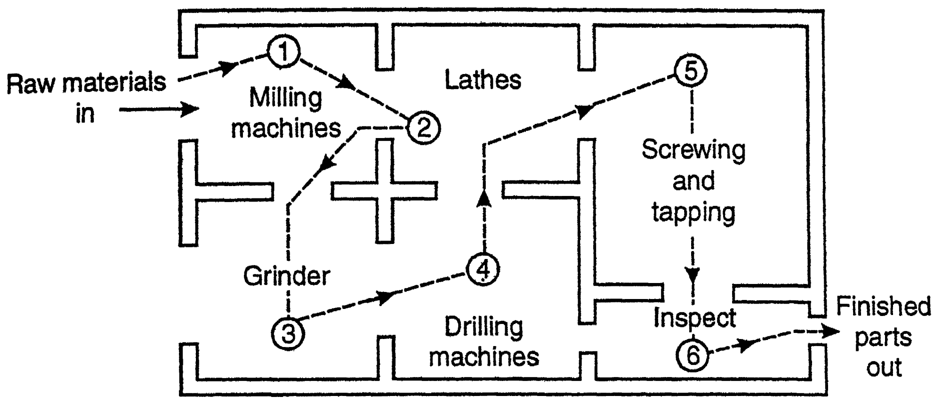


Fig. 7.10. Process layout.

7. Higher level of individual operator performance.
8. Changes in the sequence of operations are not disruptive and can be incorporated with minimum inconvenience.
9. It provides better control of total manufacturing costs.
10. There is less interruption in work flow due to machine breakdown.
11. A lower proportion of fixed costs to total costs.

Disadvantages :

1. It groups the machines functionally in such a way that the cost of material handling is increased.
2. It involves difficulties in routing, scheduling and controlling the manufacture of products because of the almost endless combinations of sequences that often can be used in processing similar items.
3. It entails more difficult control as well as more costly supervision inside and outside the 'shop' or 'department'.
4. Co-ordination and control are difficult because of manufacturing variations.
5. A plant breakdown in one department may sterilise the work of other departments, which means the wastage of time and effort.
6. It is difficult to trace the final responsibility for the finished product as the work has to move through different departments during its processing.
7. Requires more skilled labour and entails difficulty in labour procurement.

2. Product layout. In this layout, machines and other manufacturing facilities are located in the sequence required to manufacture the product. Thus if the sequence of operations for a

given part consists of drilling a hole, milling a slot, and forming the part, then the arrangement or layout of machines to manufacture this part would consist of, first, a drill press to drill the hole; next, a milling machine to mill the slot; and last a press to form the required part. In effect the operations necessary to fabricate the part are determined and the machines are then placed in the sequence needed to effect these operations. It is also called *straight line layout.*

This type of layout mostly and best suits those industries which manufacture a large volume of standard products involving repetitive processes.

Fig. 7.11 shows a typical product layout.

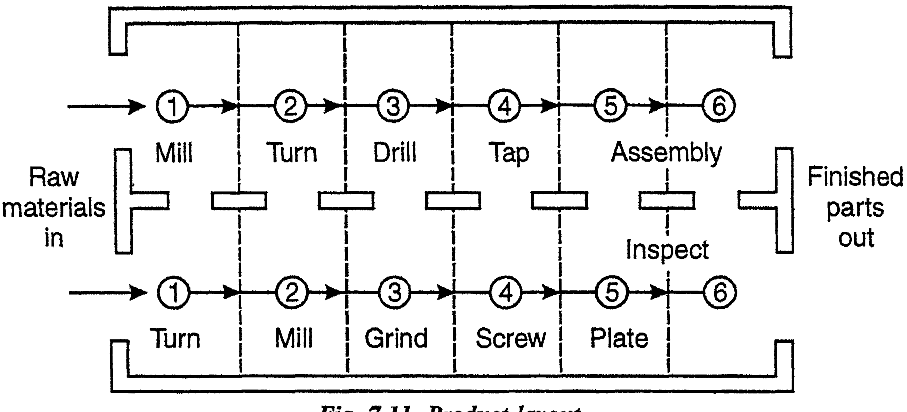


Fig. 7.11. Product layout.

Advantages :

1. It makes more automation applicable.
2. It allows for labour specialization.
3. It needs reduced manufacturing area.
4. Simpler production control and reduced total inspection.
5. More utilisation of unskilled persons.
6. Labour and material flow can be controlled easily.
7. Reduced materials handling costs.
8. It results in lower manufacturing costs.
9. Low cost labour and ease of procurement and training.
10. Requires less inspection.

Disadvantages :

1. Specialised facilities require a high initial investment.
2. It entails high aggregate overhead cost.
3. The arrangement leads to an inflexible layout and as such cannot be adopted to the manufacture of any other type of product.
4. Even a minor change in the machine arrangement means rather a complete change in layout.
5. This layout involves such grouping in a continuous line that machine breakdown at any point along the line will lead to stoppage of the entire line of machines.
6. Supervision is more difficult.

Combined Process and Product Layout. Product layout and process layout are the classic types of layout but they are more often found in combination than in their pure forms. For example, a plant may use process layout in the manufacture of the component parts for an item but assembling and testing of the item may be carried out on a product layout basis.

A proper layout is one which contributes most effectively the economical flow of material through the sequences of the manufacture.

7.11. PRODUCTION, PLANNING AND CONTROL (PPC)

7.7.1. Definitions

Production. *It involves sequence of operations that transform raw materials into the desired shape and size.* Transformation in an industry is done by carrying out a number of operations.

Planning. *It begins with the analysis of given data, on the basis of which a scheme of utilisation of firm's services can be outlined so that the desirable target may be achieved in an efficient manner.*

Control. *It involves supervising operations with the aid of control mechanisms and feedback information about the progress of work.*

7.11.2. Functions of PPC

The various *functions* of PPC are :

(*i*) Forecasting
(*ii*) Order writing
(*iii*) Product design
(*iv*) Process planning and routing
(*v*) Material control
(*vi*) Tool control
(*vii*) Loading
(*viii*) Scheduling
(*ix*) Despatching
(*x*) Progress reporting
(*xi*) Corrective action.

7.11.3. Advantages of Production Control

1. More effective use of man power and equipment.
2. Lost time of works cut to a minimum.
3. Overtime cut considerably.
4. More efficient purchasing of materials results in smaller raw materials inventory.
5. Good for morale of workers.
6. Definite delivery dates can be maintained.

7.11.4. Constituents of Production Control

The main *constituents or techniques of production control* are :

1. Production planning.
2. Routing.
3. Scheduling.
4. Despatching.
5. Follow up.

1. Production Planning. Production planning covers a careful and exhaustive study a pre-arranging of the technique involving a long and complicated series of separate operations so that the required product of the right quantity may be manufactured at the right time and at the most economic cost. It is aimed at achieving a manufacturing output that will achieve one or more of the following *objectives.*

(*i*) Capture a desired share of the market demand.
(*ii*) Operate the plant at a predetermined level of efficiency.
(*iii*) Bring a prescribed level of profit.
(*iv*) Create a specific number of jobs.
(*v*) Utilise available plant facilities.

A balanced production planning provides the following *advantages* :

(*a*) Increases operating efficiency by stabilising productive activities,
(*b*) Facilitates selling and customer service,
(*c*) Helps reduce production cost by providing reliable basis for investment in raw materials and tools, and
(*d*) Promotes fuller utilisation of plant, equipment and labour by controlling all time and efforts essential in manufacture.

Functions of planning department. Planning department *performs* the following *functions*:

(*i*) It lays down the production schedule in advance, drafts designs, specifications and instructions for each Works Order and also determines the routing of operations through the plant.

(*ii*) It decides the quantity and quality of materials required, specifies the appropriate tools and machines to be used, and in some cases, fixes the rate of wage payment.

(*iii*) It determines the grade of labour required, the quantity of output to be produced on each Works Order; and regulates the allocation and distribution of work amongst the different groups of men and machines so as to enable each task to be completed within its scheduled time.

(*iv*) It is always on the constant lookout for any improvement in machinery or tools, or variation in existing methods of operation, as would tend to give more efficient results.

(*v*) It decides what should be most economic size of each unit of production in execution of large or small orders.

2. Routing. Routing *means determination of path on which manufacturing operations will travel establishing the sequence of such operations and looking to the proper category of machines and personnel which these operations will require.* It is a technical function in the first instance and is originally performed by the methods or engineering department. Routing includes the following *steps* :

(*i*) The analysis of the finished article from the manufacturing standpoint, including the determination of components if it is an assembly product.

(*ii*) The fixing of the sequence of completion in manufacture that one part or piece of material bears to another in order that all may be brought together as needed in the process of manufacture.

(*iii*) Determination of manufacturing operations and establishing their sequence for their performance.

(*iv*) Determination of process time in respect of each individual operation and the class or number of machines required for manufacturing the articles.

(*v*) The division of total quantities required into proper manufacturing lots or batches. This should be done with particular reference to (*a*) length of operations, (*b*) space occupied by the material while moving through the shop, and (*c*) the requirements of the master schedule.

(*vi*) Determination of scrap factors leading to spoilage or shrinkage.

(*vii*) Preparation of the forms to be used by the plant departments.

3. Scheduling. Scheduling *means the determination of the relative time at which each operation or event in connection with manufacturing is to occur.* It furnishes a logical time table which shows when work will be released to the plant in a prescribed order in the proper sequence.

Scheduling procedure. *'Master schedule'* and *'Production schedule'* usually provide the base for carrying out scheduling.

Master schedule (*i*) provides the production manager relevant statistics so that arrangements may be made to meet delivery and sales commitments; (*ii*) assures the utilisation of plant capacity in an effective and logical order, and; (*iii*) helps calculation of machine loading.

For preparing the master schedules a specified date of delivery according to the contract with the customer is fixed. Beginning at that date and measuring backward a series of dates is set fixing the latest time on which important features of the work must be completed if the delivery date is to be met. In the schedule, the heavy horizontal lines indicate the scheduled time; the heavy broken lines show whether the work is upto schedule, behind the schedule or ahead of schedule.

Production schedule is that schedule which provides a time table showing when the detailed operations of manufacture will start and when the same will finish. Thus it is a bridge spanning the gap existing between the 'starting' and 'finishing' time involved in the performance of the detailed operations of manufacture embracing two considerations : *order of priority* and *proper sequence.*

The *limitations* of production schedule are : (*i*) Required materials, and parts which will be purchased. Such materials and parts must be available to process the materials which find their way on the schedule. (*ii*) Availability of plant facilities required for processing. (*iii*) Availability of right type of personnel required for the performance of the work which is being scheduled.

The *objectives* of production schedule are : (*i*) Production schedule should be so designed as to dance to the tunes called by the master schedule; (*ii*) To set a constant supply of work in advance so that each machine may be kept engaged in relation to its production capacity; (*iii*) To complete manufacturing orders in the most economical time coupled with correct sequence and proper relation.

4. Despatching. When routing and scheduling of a product have been completed, there still remains the job of despatching. *The despatching function involves the actual granting of*

permission to proceed according to plans already laid down. It is the contact between planning and operation. It carries out the physical work which has been planned by scheduling. Despatching actually means day to day control of the work in progress, to issue daily instructions or work orders, move orders, checkup receipt of materials, issue of materials, assigning of particular persons to particular machines every day. So far 'routing' meant laying down operations and their sequence in advance, 'scheduling' meant the timing of different operations through different machines, men and materials whereas dispatching actually controls the activity on the spot, co-ordinates what has been planned and sees to it everything goes on smoothly.

5. Follow up. The *final step* in production control is the checking or *follow-up stage.* This includes reporting production operations as they take place and investigating variances from the operation schedules in an effort to assure a close connection between planned and actual production. The expediter is ever on the alert for bottlenecks caused by breakdowns of equipment, lack of proper tools or material, labour difficulties or absences, lags in speed on some operations as compared with others, excessive production of defective parts, and other causes of description in the planned scheduled of factories activities.

Gantt charts. The Gantt chart is one of the fundamental charts used in a manufacturing concern. It is especially valuable in production control. It was originated by H.L. Gantt during world war I.

The underlying principle of a Gantt chart is to schedule and then measure the progress of different jobs in the different periods scheduled to complete the same. A schedule of work to be carried out in a department is prepared for a number of weeks in advance after taking into considerations the orders in hand, raw materials and on order, the number of workmen in the department, the capacity of the machines and various other factors that may be applicable in a given case in preparing such a schedule. Table 7.1 presents an example of such schedule and its data is incorporated in Fig. 7.10.

TABLE 7.1

	Jobs scheduled	*Jobs completed*
1st week	80	70
2nd week	60	80
3rd week	100	80
4th week	120	100
Total	**360**	**330**

TABLE 7.2

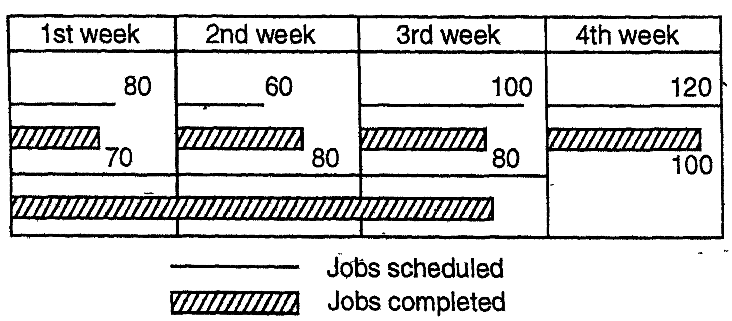


Fig. 7.10. Progress chart.

As shown in the Fig. 7.10 the schedule of work in number of jobs for each week is indicated by fine horizontal line while the hatched bar (drawn parallel to fine line) represents the number of jobs completed during one week. When the number of jobs produced is more than the jobs shown in the schedule the length of the bar will be more than that of the fine line indicating the schedule and when completed jobs' number is less, the bar will fall short of the fine line showing the schedule. The continuous fine line and hatched bar represent the total number of jobs scheduled and completed for a period of four weeks. In such a chart, the width of the daily space usually represents the standard task or schedule of work rather than time because spaces on the chart representing time can be converted in the ultimate analysis into work units or represents amounts that can be produced in that time.

Gantt charts in actual practice are used in the following five typical forms :

1. Planning, 2. Load, 3. Machine idleness, 4. Man idleness, 5. Progress.

QUESTIONS WITH ANSWERS

Q. 7.1. (*a*) What is a process ?

(*b*) What are the general categories of manufacturing ?

Ans. (*a*) A **process** *is simply a method by which products can be manufactured from raw materials.* Any product that we use is processed in some form or the other.

(*b*) The *general categories of manufacturing* are :

1. Casting and moulding.
2. Cutting.
3. Forming.
4. Assembly.

Besides these processes the final operation on a product could be a finishing process which includes :

- Heat treatment
- Plating
- Cleaning
- Painting.

Q. 7.2. What are the functions of a process engineer ?

Ans. The *functions of a process engineer* are as follows :

1. To determine the basic manufacturing process.
2. To determine the order of sequence of operations necessary to manufacture in terms of operation routing, process details and process pictures.
3. To specify production tolerances on blanks and on auxiliary surfaces.
4. To specify the process parameters for the various manufacturing operations selected.
5. To determine the order tooling and inspection gauges require to manufacture the part.
6. To determine and select the equipment needed to manufacture the part.
7. To provide the necessary decircumentation to be used by the shop people.
8. To specify the methods and means of inspection depending upon the accuracy desired.

Q. 7.3. What is a 'Product Cycle' in manufacturing ?

Ans. The impetus of a new product or a revision of an existing product may come from sources such as sales and marketing people or maintenance and service people based on their contact with the consumers or the market demand. Then the product (design) engineering staff based on their expertise and constraints such as appearances, functions, durability, cost and ease of maintenance would design the product and provide the following details :

1. *Build models for testing.*
2. *Provide part prints :*
- Physical dimensions
- Material
- Special finishing required.
3. *Provide tool design and construction aids :*
- Master layouts
- Templates
- Master models.
4. *Provide production rates and release dates.*

The process engineering takes place directly after product engineering has completed the design of a product. From the information received it creates the plan of manufacture. Processing is then the function of determining exactly how a product will be made to satisfy the requirements specified at the most economical cost.

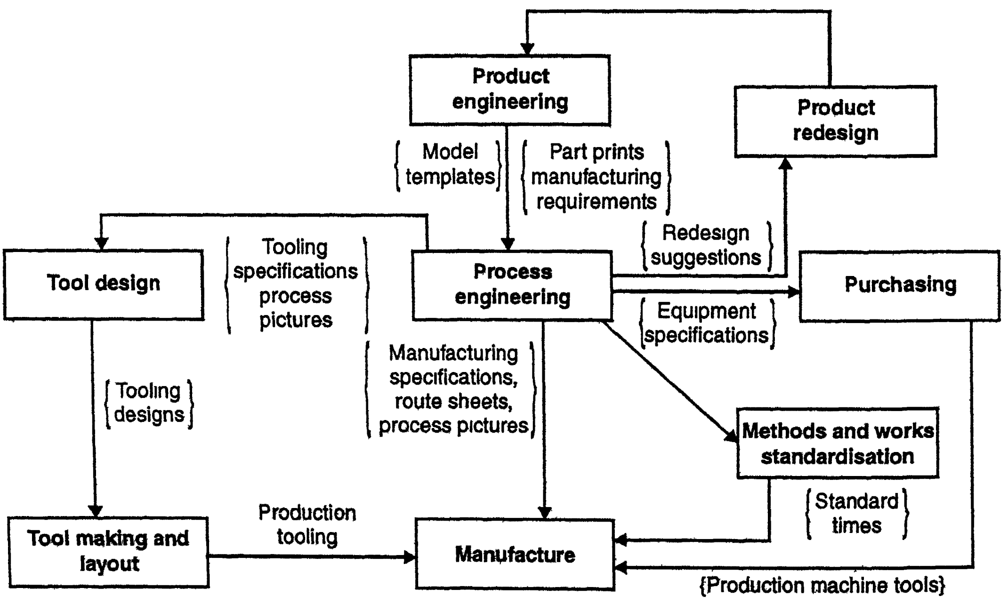


Fig. 7.11. Product cycle in manufacturing.

Q. 7.4. Explain briefly "Process engineering function" ?

Ans. • The *process engineering function* (See Fig. 7.11) *forms the heart of the total manufacturing operation.* It interacts with practically all areas of the total manufacturing situation.

- In *large companies*, the process engineering function is of a magnitude of a separate department. This department has many process engineers who specialise in this work. Each process or methods engineer may further specialise by dealing with only one of the products being manufactured.

  In *smaller companies*, the process engineer may work in a department having other functions as well. In fact, in very small organisations, the title of a process engineer may not exist. The function of process engineering is carried out as a part time job by one or more individuals. Alternatively in large organisations each separate department may have its own group of process engineering staff to cater to their products only.

  The function of process engineering, in whatever way it is organised, must be present in all manufacturing industries.

Q. 7.5. What is the difference between process planning and operation planning ?

Ans. Process planning :

The task of process planning consists of *determining the manufacturing operations required to transform a part form a rough to the finished status specified on engineering drawing.* Fig. 7.12 shows the *specific activities or steps* involved in determining the manufacturing plan for converting a part from a rough to a finished condition.

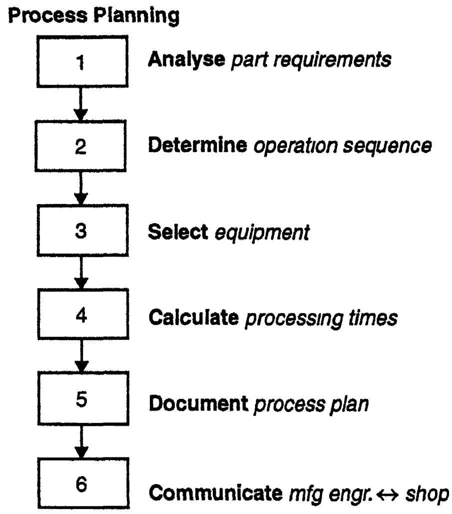


Fig. 7.12. Steps/activities involved in process planning.

1. *'Analyse' part requirements.* The part's requirements defining its features, dimensions and tolerance specifications will determine the corresponding processing requirements. These requirements will include not only the operations involved in generating part shape but likewise operations encompassing inspections, testing, heat treating, surface coating and packaging.

2. *'Determine' operation sequence.* This step involves determining the sequence of operations required to transform the features, dimensions and tolerances on the part from a rough to finished state. This helps in determining the type of processing operation that has the capability to generate the various types of features given the tolerance requirements.

3. *'Select' equipment.* In this step, a specific piece of equipment is selected to accomplish the required operations. Selection of the machine is determined based on size and tolerance capabilities, economics, availability and capacity considerations.

4. *'Calculate' processing times.* This step involves calculation of the specific operation set-up times on each machine. After this appropriate times for part loading, unloading, machine indexing and other factors involved in one cycle for processing a part are included.

Steps 5 and 6 then follow, as the need be.

Operation Planning :

- **Operation planning** is *that stage in planning which marks the completion of routing at process planning level.* The operation planning in concerned with planning the details of the method to be used to complete each operation at its chosen work center and with designing the necessary tooling.
- Operations are divided into work elements. The record used to show the planned sequence of work elements is generally known as an *operation sheet.* It is in effect a record showing how an operation should be carried out.
- The *purpose of operation sheet is to record and communicate information that is essential for making each part.* This is the sole determinant and criterion for the design of the form that will be used. It is intended to achieve a level of specification that can be coated, evaluated and altered in specific rather than in abstract terms.
- Operation sheets are prepared for each part, sub-assembly and assembly. They *indicate the route of the parts* through the various departments, the sequence of required operations, the machines, special tools and gauge needed, the time required to do each operation, the details of speeds, feeds etc.

Q. 7.6. Explain how the 'product design' and 'product manufacturing' take care of the environmental protection.

Ans. The *'product design'* and *'product manufacturing'* take care of the environmental protection *by adopting suitable measures.*

Example. During Activity Analysis step of design, which is an Input-Output analysis, the designer estimates the desirable and undesirable inputs and outputs from the design. Any undersiable output such as noise, vibrations, poisonous emissions, glare etc. are estimated at the design stage itself. Production people also participate in the production design stage to support factors which do not create environmental pollution. *Foundaries are now-a-days being replaced by fabrication plants to minimise pollution.*

Q. 7.7. Describe the independent and dependent variables of a production system.

Ans. A production system can be looked upon as an input-output system in which raw materials, equipments and human resources are the inputs to the system. The outputs are product or service to market. Apart from the *internal system variables* which **depend** wholly upon the management, there are **independent** or exogenous variables such as *market conditions, competitors, government laws* etc. which are important and decide the success of any business.

Q. 7.8. On what considerations manufacturing processes are selected for a given product?

Ans. Producing design of any product is a critical link in the chain of events that starts with creative ideas of design and ends with final and successful product in the market place. In modern technological age the function of production is not a routine activity. Rather we can say that *design, material selection and processing are closely related each other* as shown in Fig. 7.13.

When form of any product is being developed, it becomes important to identify materials and production techniques and to be aware of their specific engineering requirements. An experienced designer already has in mind during design phase the short list of materials and

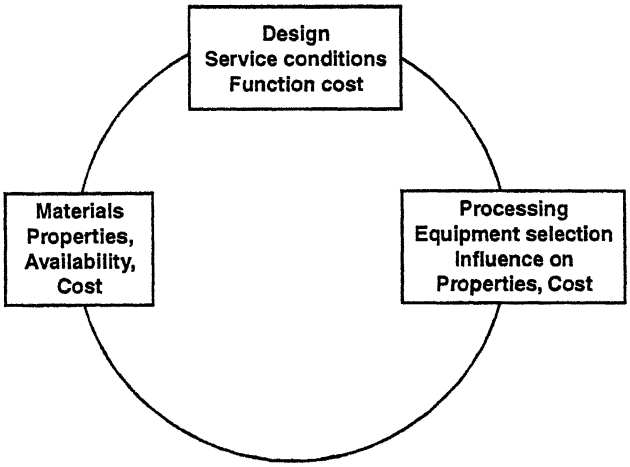


Fig. 7.13.

processes. The important points to be considered for selection of manufacturing processes to be used are mentioned below :

1. The quantity of product to be developed.
2. Prior use knowledge for similar applications; this knowledge can be both blessing and a curse.
3. Knowledge and experience.
4. Availability of material and process.

The following list of factors also influence selection of manufacturing process :

(*i*) Cost of manufacture
(*ii*) Quantity or pieces required.
(*iii*) Material
(*iv*) Geometric shape
(*v*) Surface finish
(*vi*) Tolerance
(*vii*) Gauges
(*viii*) Tooling jigs and fixtures
(*ix*) Available equipment
(*x*) Delivery date.

- The selection of a best possible manufacturing process is not an easy task. Rarely can a product be made by only one method, there are several competitive processes available. Since in all engineering design cost is very important factor, therefore, the

selection of optimum manufacturing process depends largely on the costs of manufacture by the competing processes. The evaluations not only depends upon the cost of processing the material to the finished product but also the material utilisation factor and the effect of processing method on material properties and the subsequent performance of parts in service.

Q. 7.9. Discuss with examples the following types of manufacturing systems :
(*i*) Discrete manufacturing;
(*ii*) Continuous manufacturing.

Ans. (*i*) **Discrete manufacturing :**

"Discrete manufacturing system" is typified by the intermittent or interrupted flow of material through the plant.

- It makes use of general purpose machines and produces components different in nature and in small quantities.
  Machine-shops, repair and maintenance-shops, welding shops etc. are some of the *examples of intermittent production.*
- Intermittent production or discrete manufacturing can be *classified* as :
  (*a*) Batch production or manufacturing.
  (*b*) Job manufacturing

(*ii*) **Continuous manufacturing :**

"Continuous manufacturing" involves a continuous or almost continuous physical flow of material.

- It makes use of special purpose machines and produces standardized items in large quantities.
- Chemical processing, Cigarette manufacturing and Cement manufacturing are some of the industries engaged in continuous production or manufacturing.

Q. 7.10. What are the features of a production system ?

Ans. The *features of a production system* are :

1. A production system is goal oriented; goal being production of goods and services.
2. The goal is achieved through technological transformation of raw material, using energy.
3. Technological transformation is carried on by a suitable choice of technique, an optimal combination of capital (machinery) and labour from the broad spectrum of techniques ranging from complete automation (all capital, no labour) to completely mannual labour (no capital, all labour).
4. Irrespective of choice of technique, specialisation or breaking down total quantum of transformation needed for goal to smaller simplified packets, so that the labour and machine repetitively perform then with reflexive (involuntary) and automatic efficiency.
5. Division of work entails corollary division of total team objectives for the sub-system, hence of authority and of responsibility.

Q. 7.11. Discuss briefly input-output model of a production system.

Ans. Owing to the complexity of the modern system it is necessary to analyse the production system on "system concept". The system concept provides a conceptual framework of production situation. It is worthwhile to put a production system in a model form which can represent all the parameters involved in the industry.

The model formulation process involves the listing of various input such as materials, tools parameters, energy requirements etc. to the production process and getting the output from the production system.

Figure 7.14 depicts the input-output model of a production system.

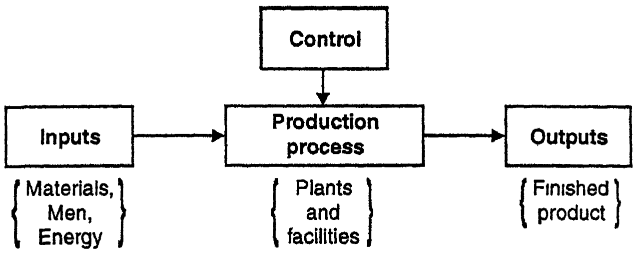


Fig. 7.14. Input-output model of a production system.

Q. 7.12. What are the advantages and disadvantages of a mass production system ?

Ans. Following are the advantages and disadvantages of a mass production system operating as a continuous flow line :

Advantages :

1. *Smooth flow of material* from one work-station to the next.
2. *Minimum material handling* (since the work-stations are so located as to cut down the distance between consecutive operations).
3. *Less space required* for the work transit and for temporary storage of material.
4. The operators *do not need special training* at the production line (as such the training is simple and inexpensive).
5. *Simple* production planning and control system can be followed.

Disadvantages :

1. Mostly it has been felt that *high investments* are needed due to the specialised nature of the machines.
2. In the event of breakdown of one machine, there will be *complete stoppage* of the remaining jobs on other machines.
3. The production pace is known by the *'slowest machine'*.
4. Maintenance and repair work becomes most difficult.
5. Originally the layout is established by the product but any changes incorporated in the product design *results in major change in the layout.*

Q. 7.13. Explain briefly a systematic approach for formulating model and solving practical problems.

Ans. Following steps are involved in a systematic approach for formulating model and

solving practical problems :

Step-1 : The first and foremost phase is to *'Define the problem'*. It should point to the exact need and should be too easy to be understood by everyone. If the definition of problem is ambiguous, it may lead to loss of time, money and labour.

- After getting the exact solution, it is to be *analysed.* For its analysis, production system with its sub-systems can be represented into graphical and schematical model for better understanding.

  All inputs, outputs and information channels are clearly drawn by block diagrams.

Step-2 : After the identification of the exact definition of problem, *process of transformation starts.*

- To start with the *alternative solutions are thought-out.* These solutions are governed by various factors influencing the production system.
- Effectiveness of the alternatives is weighed by various criteria, *e.g.,* cost, profits, investment, machine utilisation, men utilisation etc. Any of these parameters may be altered depending on the nature of criteria.
- All the variables influencing system can be categorised as *controllable* and *uncontrollable variables.* According to the nature of problem, these variables will be different. **Controllable variables** *are those that may be manipulated by management while* **uncontrollable variables** *cannot be controlled by the management.*

  Based on these variables, a *model is developed for 'effectiveness' of alternatives.*

Step-3 :

- After finding *'effectiveness',* management has to find alternative courses of action. For this, existing science and technology, research market surveys, standards, handbooks etc. in consultation with experts are consulated.
- Each of the possible alternative is evaluated and then it is accepted or rejected.

Step-4 :

- Finally, the problem is to be *analysed.* It is analysed by *evaluation of outputs of the system corresponding to given inputs in terms of effectiveness.*

In any production system, the target remains maximising the profits with minimum of additional investment. Possible methods for this aim may be the *exploitation of plant capacity to the maximum, increasing plant capacity by proper planning and also by overtime.* These three plans must be analysed. Breakeven analysis can prove very useful for the evaluation of appropriate level.

Q. 7.14. Explain briefly an Input-Output model for an automobile industry.

Ans.
- In automobile industries, the layout is *"line layout"* which is *preferred for mass manufacturing.*
- Huge quantity of output can be attained only if inputs meet with proper standards and specifications. For maintaining proper control over the process *automation is preferred* which can be attained by a systematic arrangement of electronic instruments, scanners, automatic inspection and general purpose machines.

Robots find wide application in automobile industries at those spots where atmosphere is not suitable to human beings or high speed uniform operation is to be carried out.

Figure 7.15 depicts an idea of Input-Qutput model for an automobile industry, producing cars. Inputs include a variety of raw materials which will be transformed to final products, some finished components which are to be used a such. All these finished components are assembled to give final shape of car.

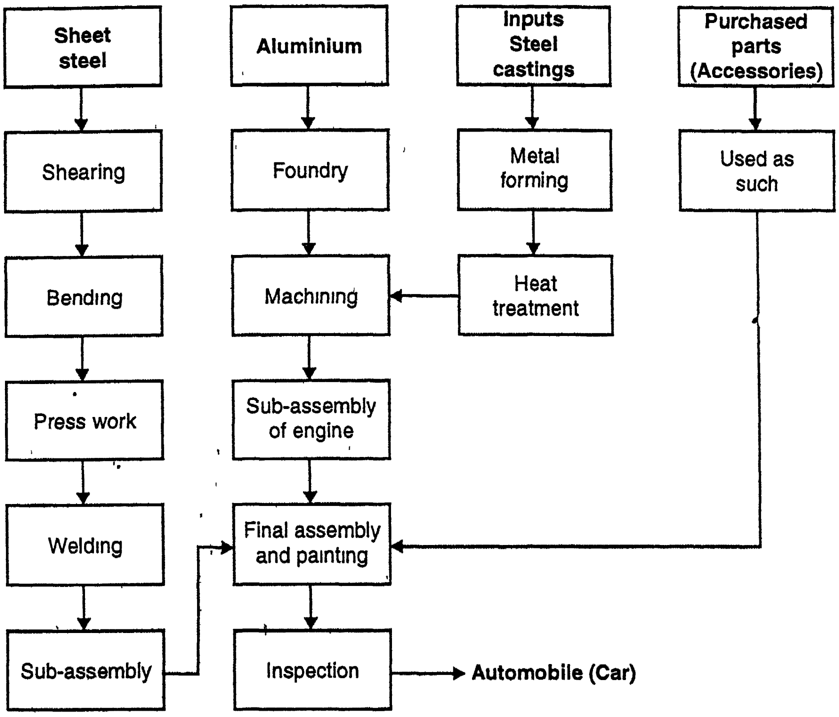


Fig. 7.15. Input-Output model for an automobile industry.

Q. 7.15. Explain briefly various feedback loops which provide information for redesign.

Ans. Following are the various feedback loops which provide information for redesign.

1. The feedback loop from *market to function analysis*. This is owing to the market needs effecting a design change.
2. Feedback loop from *production to design, i.e.,* in case the design is difficult to produce in terms of accuracy and processing.
3. Feedback loop from *prototype shop to design* — Just in case the prototype testing indicates some need for design alteration due to insufficient performance of the prototype from the point of view of various standards of performance.

Q. 7.16. How will you classify the manufacturing processes ? Describe the important points to be observed while designing for heat treatment.

Ans. Manufacturing processes are broadly *classified* as follows :

1. ***Primary processes :***
   - Casting

- Welding
- Rolling etc.

2. *Secondary processes* .... These give final dimension.
   - Machining
   - Forging
   - Die casting
   - Grinding and abrasive processes etc.

Design for heat treatment :

Parts which have to undergo heating and cooling cycle should be designed so that during cooling, deformation, cracks, stress concentration should be avoided. Sharp corners, sudden change of cross-section, under-cut should also be avoided in the parts to be heat treated.

Q. 7.17. Explain what do you understand by 'Product Engineering' and 'Process Engineering' ? Outline the scope of each.

Ans. Product engineering. It refers to *various parts of a product and their specifications* and how they are inter-related to each other; size tolerances and other specifications also come under this.

The *scope of product engineering* include the following :

- Product life cycle;
- Product profit planning;
- Product improvement and development;
- Design for competitive advantages.

Process engineering. It refers to the *analysis and control of processes* involved in manufacturing a product; how the process takes place step-by-step, its time schedule, machine working, all other aspects related to processing. Now-a-days it can be done through a computer also.

The *scope of process engineering* include the following :

- Process planning;
- Selection of machines and machine tools;
- Planning of operation sequence;
- Process sheets etc.

Q. 7.18. Explain the meaning of 'designing for production'.

Ans. *'Design for production'* is establishing the shape of the components to allow for efficient high quality production for meeting with buyer's satisfaction.

The key concern of the design for production is in specifying the best manufacturing process for the component (or part of product) and ensuring that component form supports the production process.

Q. 7.19. Explain how designing for production rules help in speedy production, with minimum scrap of parts requiring :

(*i*) Cutting of external threads;

(*ii*) Drilling of holes on standing surfaces.

Ans. (*i*) **Cutting of external threads :**

1. External threads made by all processes *should not terminate too close to a shoulder* or other large diameter. Space must be provided for threat cutting tool.
2. The *length* of threads should be kept *as short as possible*, consistent with the function requirement of the part.
3. Slots, cross holes and flats *should not be placed* where they *intersect* screw threads.
4. Tubular parts must have a *wall heavy enough to withstand* the pressure of the cutting or forming action.

(*ii*) **Drilling of holes :**

1. The drill entry surface should be *perpendicular to* the *drill bit* to avoid starting problems and to help in the proper location.
2. The exit surface of the drill also should be *perpendicular to the axis of the drill* to avoid breakage problems if the drill leaves the work.
3. If the straightness of the hole is particularly critical it is best *to avoid interrupted cuts* unless a guide bushing can be placed at each re-entry surface.
4. It is *best to use standard drill sizes* when even possible to avoid the added cost of special drill grinding.
5. *Through holes are preferable to build holes.*
6. When blind holes are specified, they should not have flat bottoms.
7. *Avoid deep holes* (over 3 times the diameter).
8. *Avoid designing parts, with very smaller holes.*

Q. 7.20. What are the factors to be considered for ease of manufacturing ? Explain with suitable examples.

Ans. Product development and design should consider whether geometrically a design has a good compatibility with material and production process for making a producible design. A typical *example* is that of a *pulley* in which curved arms are provided so that during production there are no casting problems and high tensile stresses being set up in the arms during casting solidification are prevented. Therefore, it is always suggested to take care of production process involved in manufacturing the required product in designing the product.

Design for manufacturability. A product design should be such that it is easily producible by the production process. Design for production or manufacturability is a topic of importance in product design. Each production process and corresponding design configuration that can be easily produced is considered in brief.

1. Design for casting. Casting is a solidification process. There would have been no problem if every portion of a casting were solidified at the same time. Such a situation is only an ideal one. In practice products have cross-section so designed that there are heavy sections where loading in that portion is more and vice versa. A pulley with straight arms has problem during solidification due to the heavy rim portion and boss portion putting tensile stresses on the straight arms during cooling. This causes 'hot tear'. Thus pulley arms are made *curved for enhanced flexibility.*

Likewise, junctions such as T, V, Y create problems due to less volume ratio at the junction.

Sudden variation in thickness of material is harmful to castings. Gradual changes are provided by designer in such area. Sharp corners are avoided and radius is provided.

2. Design for forging. Closed die forgings are produced due to compression of material between upper and lower half of the dies. In order that material may flow freely in die cavities, there should be *no transitional surfaces* such as intersection of cylinder and rectangle etc. in a properly designed part. Otherwise this part cannot be manufactured easily due to problem of filling of die cavity.

3. Design for machining. Component design for each of machining should be such that:

(*i*) The *ample overtravel* is available to the tools;

(*ii*) The tools should *not get unbalanced* in drilling of inclined surfaces;

(*iii*) As much as possible machining should be done *in one pass* to avoid time wastage;

(*iv*) A good design should *minimise machining to a minimum.*

4. Design for sheet metal parts. Shapes of sheet metal parts should ensure that minimum wastage of valuable sheet metal should be in scrap form. *'Nesting technique'* is very important in strip layouts of sheet metal parts design. *Operations such as deep drawing should be avoided.*

There is modern trend to combine welding alongwith bending operation to produce surfaces of revolution which were initially produced by tube sinking and deep drawing.

5. Design for powder metallurgy. Parts produced from powders and particulate processing should be purely *prismal, i.e.,* there is no need to provide a draft as in case of casting/forgings. The male and female dies have a nice sliding fit and produce a dense and strong component.

Q. 7.21. What are the design rules for manufacturing and ease of assembly ?

Ans. The *design rules for manufacturing and ease of assembly* are listed below :

1. Develop a modular design.
2. Design for minimum number of parts.
3. Minimise part variations.
4. Design parts to be multifunctional.
5. Design parts to be multiuse.
6. Design parts for ease of fabrication.
7. Avoid non-standard fasteners.
8. Minimise assembly directions; preferably top down.
9. Maximise compliance in parts; make assembly easy through chamfers, leads, tapers.
10. Evaluate assembly sequence for efficiency.
11. Improve component accessibility.
12. Avoid flexible components as they are difficult in automated assembly.
13. Allow for maximum intolerance of parts.
14. Use known vendors and suppliers.
15. Use parts at derated values of stress for increased reliability.
16. Minimise sub-assemblies.
17. Use new technology only when necessary.
18. Emphasize standardisation.
19. Design components for symmetry from end to end and about axis insertion.
20. Use the simplest operations with known capability.

Q. 7.22. What factors affect the quality of a product ?

Ans. The following *nine M's* directly affect the quality of products and services and so these should be identified and dealt with appropriately to obtain good results :

1. Material
2. Manpower
3. Money
4. Market for products, services
5. Motivation of employees
6. Modern information approaches
7. Management
8. Machines used
9. Mounting product needs.

HIGHLIGHTS

1. *Manufacturing* is the economic term for making goods and services available to satisfy human wants.
2. Any system that produces useful products or services, in general, is called a *Production system.*
3. *Production* may be considered as a process of transformation of a set of input elements whereby the utility of goods or services increased.
4. *Process type manufacturing* involves continuous flow of materials through a series of process steps to obtain a finished product like chemicals.
   Fabrication-type manufacturing involve manufacturing of individual parts or components by a series of operations, such as rolling, machining and welding.
   In *Assembly-type manufacturing* the parts or components are put together to get a complete product, such as a machine.
5. The manufacturing processes are *classified* as :
   (*i*) Constant mass processes
   (*ii*) Metal removing processes
   (*iii*) Metal addition processes.
6. Methods used for manufacturing system analysis :
   (*i*) Linear programming
   (*ii*) Waiting line model
   (*iii*) Network models
   (*v*) Statistical techniques
7. Types of production :
   (*i*) Job order production
   (*ii*) Batch or quantity production
   (*iii*) Mass production.
8. A *system is an arrangement of physical components* connected or related in such a manner as to form and/or act as an entire unit.

A *control system* is an arrangement of physical components connected or related in such a manner as to command, direct or regulate itself or another system.

9. Control systems are classified as :
   (*i*) Open-loop control systems (Unmonitored or non-feedback control systems).
   (*ii*) Closed-loop control systems (Monitored or feedback control systems).
   A closed-loop control system operating without human operator is called an *automatic control system.*
10. *Organisation* is defined as a systematic coordination and combination of the efforts with the aid of the money, men, machinery, materials and methods in a manner as would result in maximum manufacturing efficiency with minimum cost.
   Administration is defined as the effectuation of the purpose by means of organisation and is concerned with "carrying out" policies, rules, regulations and designated methods.
   Management is defined as the art of creating industrial relations of any kind, between people engaged in industry, *viz.*, relations between employers and employees, relation between individuals entering into commercial contracts, relation between investors and debtors etc.
11. *Scientific management* may be defined as a systematic approach to manage the enterprise on the basis of observation, experimentation and national decisions.
12. *Plant layout* may be classified as :
   (*i*) Process layout : It is suitable for job order plants which involve non-repetition processes.
   (*ii*) Product layout : This type of layout mostly and best suites those industries which manufacture a large volume of standard products involving repetitive processes.
13. *Production* involves sequences of operations that transform raw materials into the desired shape and size.
   Routing means determination of path on which manufacturing operations will travel establishing the sequence of such operations and looking to the proper category of machines and personnel which these operations will require.
   Scheduling means the determination of the relative time at which each operation or event in connection with manufacturing is to occur.

OBJECTIVE TYPE QUESTIONS

Fill in the blanks or say "Yes" or "No" :

1. .... is the economic term for making goods and services available to satisfy human wants.
2. Any system that produces useful products or service, in general, is called a .... system.
3. .... may be considered as a process of transformation of a set of input elements whereby the utility of goods or services increased.

4. The manufacturing processes are collected together to form a .... system.
5. Manufacturing is the heart of the system where material is converted from one form to another and value is added.
6. .... manufacturing involves manufacturing of individual parts or components by a series of operations such as rolling, machining and welding.
7. In Assembly-type manufacturing the parts or components are put together to get a complete product, such as a machine.
8. Casting is a metal removing process.
9. Powder metallurgy processing is a constant mass process.
10. Wire drawing is a metal removing process.
11. Welding is a .... addition process.
12. Thermit welding is a metal forming process.
13. Process planning is a fundamental part of industrial activity.
14. .... planning aims at planning method or series of methods for economic manufacturing of a product of the quality called for by the drawings or specifications laid down.
15. Linear programming is one of the methods of .... system analysis.
16. Waiting is always associated with costs.
17. In general, simulation models follow a conceptual structure and may not lead to optimum answer.
18. .... production consists of small scale production to meet the attainment of individual customers.
19. Batch order or quantity production is a special type of production.
20. Mass production means a continuous production without loss of time.
21. Job order production is carried out .... factories and suits for .... works.
22. A .... is an arrangement of physical components connected or related in such a manner as to form and/or act as an entire unit.
23. Each system may have a large number of sub-systems.
24. A .... system is an arrangement of physical components connected or related in such a manner as to command, direct or regulate itself or another system.
25. .... control system is one in which the control action is independent of the desired output.
26. .... control system is one in which the control action is somehow dependent on the output.
27. Liquid level control system is example of open-loop control system.
28. Traffic signal system is an example of closed-loop control system.
29. Automatic wasting machine is an example of .... control system.
30. Human being reaching for an object is an example of closed-loop system.
31. A closed-loop control system operating without human operator is called an .... control system.
32. Automatic control system has a tendency to overcorrect errors which may result in oscillations of constant or changing amplitude.

33. .... is defined as systematic coordination and combination of the efforts with the aid of the money, men, machinery, materials and methods in a manner as would result in maximum manufacturing efficiency with minimum cost.
34. .... is the evaluation of the purpose by means of organisation and is concerned with "Carrying out" policies, rules, regulation and designated methods.
35. .... is the art of creating industrial relations of any kind, between people engaged in industry, *viz.*, relations between employers and employees, relation between individuals entering into commercial contracts, relation between investors and debtors etc.
36. A plant is a place, where men, materials, money equipment, machinery etc. are brought together for manufacturing products.
37. .... organisation is also called scalar or military type organisation.
38. Functional type of organisation divides the responsibility according to the functions to be performed and not in departments or sections of the works.
39. .... management may be defined as a systematic approach to manage the enterprise on the basis of observation, experimentation and rational decisions.
40. Ensuring steady flow of standard goods to customers at fixed price is one of the aims of scientific management.
41. Organising is one of the activities of ....
42. Transport facilities is not an important factor affecting plant location.
43. Flexibility is are of the sound principles of plant layout.
44. Process layout is sometimes called .... layout.
45. .... layout is suitable for job order plants which involve non-repetitive processes.
46. In .... layout, machines and other manufacturing facilities are located in the sequence required to manufacture the product.
47. Product type of layout mostly and best suits those industries which manufacture a large volume of standard products involving repetitive processes.
48. A proper layout is one which contributes most effectively the economical flow of material through the sequences of the manufacture.
49. .... involves sequences of operations that transform raw materials into the desired shape and size.
50. .... begins with the analysis of given data, on the basis of which a scheme of utilisation of firm's services can be outlined so that the desirable target may be achieved in an efficient manner.
51. Control involves supervising operations with the aid of control mechanisms and feedback information about the progress of work.
52. .... means determination of path on which manufacturing operations will travel establishing the sequence of such operations and looking to the proper category of machines and personnel which these operations will require.
53. .... means the determination of the relative time at which each operation or event in connection with manufacturing is to occur.

54. 'Master schedule' and 'Production schedule' usually provide the base for carrying out scheduling.
55. The Gantt chart is one of the fundamental charts used in a manufacturing concern.

ANSWERS

1. Manufacturing	2. production	3. Production
4. manufacturing	5. Yes	6. Fabrication-type
7. Yes	8. No	9. Yes
10. No	11. material	12. No
13. Yes	14. Process	15. manufacturing
16. Yes	17. Yes	18. Job order
19. No	20. Yes	21. small, variety
22. system	23. Yes	24. control
25. Open-loop	26. Closed-loop	27. No
28. Yes	29. Open-loop	30. Yes
31. automatic	32. Yes	33. Organisation
34. Administration	35. Management	36. Yes
37. Line	38. Yes	39. Scientific
40. Yes	41. management	42. No.
43. Yes	44. functional	45. Process
46. product	47. Yes	48. Yes
49. Production	50. Planning	51. Yes
52. Routing	53. Scheduling	54. Yes
55. Yes		

THEORETICAL QUESTIONS

1. List the activities and operation involved in manufacturing.
2. Distinguish between production and 'production system'.
3. Depict a manufacturing system as an input-output system.
4. Name the five district stages through which the present day 'manufacturing system' has evolved.
5. Enumerate the principal types of manufacturing.
6. How are manufacturing processes classified ?
7. How is right type of manufacturing process selected ?
8. What points should be considered for selecting a manufacturing process ?
9. What is "Process planning" ?
10. What are the purposes of process planning ?
11. Explain briefly the methods employed for the analysis of a manufacturing system.
12. Enumerate the types of production.
13. Explain briefly the following types of production :
    (*i*) Job order production (*ii*) Batch or quantity production
    (*iii*) Mass production.

14. How is a 'system' defined ?
15. What is a 'control system' ?
16. Enumerate and define the elements of a control system.
17. Give five examples of control system applications.
18. How are control systems classified ?
19. Give the comparison between 'Open-loop' and 'Closed-loop' systems.
20. What is an 'open-loop' control system ? Enumerate and explain the elements of an open-loop control system.
21. State the advantages and limitations of open-loop control system.
22. Explain briefly the following :
    (*i*) Idle-speed control system;
    (*ii*) Open-loop word processor control system.
23. What is a 'Closed-loop' control system ?
24. What is a feedback ? What are its characteristics ?
25. What are the advantages and limitations of a 'Close-loop' control system.
26. What is an automatic control system ? Explain with examples.
27. What are the advantages and limitations of automatic control systems ?
28. Define the following :
    (*i*) Organisation; (*ii*) Administration;
    (*iii*) Management.
29. Explain briefly any two of the following organisation structures :
    (*i*) Line organisation (*ii*) Line and staff organisation
    (*iii*) Functional type organisation (*iv*) Complex organisation.
30. Define 'Scientific management'.
31. State the principles and aims of scientific management.
32. What are the functions of management ?
33. Enumerate elements of communication.
34. Name the factors which affect the plant location.
35. List the principles of plant layout.
36. What are the objectives of good layout ?
37. What are the fundamentals considerations in layout ?
38. How are layouts classified ?
39. Describe briefly the following types of layout :
    (*i*) Process layout. (*ii*) Product layout.
40. State the advantages and disadvantages of process and product layouts.
41. Explain briefly combined process and produce layout.
42. What are the functions PPC (Production Planning and Control).
43. What are the advantages of production control ?
44. Explain briefly the following constituents of production control :
    (*i*) Production planning (*ii*) Routing
    (*iii*) Scheduling (*iv*) Despatching
    (*v*) Follow up
45. Write a short note on Gantt charts.

8

Fundamentals of Casting

8.1. INTRODUCTION

Casting is perhaps the oldest method of manufacturing and *invariably the first step in the sequence of manufacturing a product.*

In this process (casting) the *raw material is melted, heated to the desired temperature and poured into the mould cavity where it takes the desired shape. After the molten metal solidifies in the mould cavity the product is taken out to get the casting.*

- *Casting is preferred* because of the following **reasons :**
  - (*i*) It is cheap and direct way of producing a shape with desired mechanical properties.
  - (*ii*) Metals and alloys, *e.g.*, highly creep resistant allays cannot be worked mechanically and can only be cast.
  - (*iii*) Casting is best suited when different properties are required in different sections of product. These are made by incorporating pre-fabricated inserts in a casting.
  - (*iv*) Cost associated in giving details by casting process is minimum whereas cost in mechanical working would be too high to produce them.
  - (*v*) Casting is preferred when components are desired in low quantities.

Basic features. The basic features common to various casting processes can be summarized as :

(*i*) *Pattern and mould.*
(*ii*) *Melting and pouring.*
(*iii*) *Solidification and cooling.*
(*iv*) *Removal, cleaning, finishing and inspection.*

8.2. PATTERNS

8.2.1. Definition

- A **pattern** is *defined as a model of a casting, constructed in such a way that it can be used for forming an impression (mould) in damp sand.*
- In making a casting the first step is to prepare a model, known as *pattern*, which differs in a number of respects from the resulting casting. These differences, known as pattern *allowances, compensate for metal shrinkage, provide sufficient metal for machining the surfaces and facilitate moulding.*

8.2.2. Pattern Materials

The various *pattern materials* are described below :

1. Wood :

Most patterns are made of *wood* (Burma teak, Pine wood, Mahogany, etc.) because of its follows *properties* :

(*i*) Cheapness.
(*ii*) Ease of availability.
(*iii*) Lightness.
(*iv*) Ease of obtaining smooth surface and preserving surface; by applying coating of shellac.
(*v*) Ability to be worked on easily.
(*vi*) Ease of joining.
(*vii*) Ease of fabricating to numerous shapes.

However, wood is *easily affected by moisture, its shape changes by change in moisture content, it wears out quickly by sand abrasion, it may warp during improper storing, it cannot stand rough usage.* Wood used for pattern making *should be properly dried and it should be straight grained and free from insects and free from excessive sap wood.*

2. Metals :

- Where durability and strength are required, patterns are made from metals — usually aluminium alloy, brass or magnesium alloy.
- For mass production, steel or cast-iron patterns may be prepared.

3. Other Materials :

Some patterns are made of *plaster, plastic compound, wax* etc.

8.2.3. Types of Patterns

Types of patterns depend upon the following *factors* :

(*i*) The shape and size of casting.
(*ii*) Number of castings required.
(*iii*) Method of moulding employed.
(*iv*) Anticipated difficulty of the moulding operation.

The following *types of patterns* are commonly used :

1. Solid or single piece pattern. 2. Split pattern

3. Loose piece pattern
4. Match plate pattern
5. Gated pattern
6. Skeleton pattern
7. Sweep pattern
8. Cope and drag pattern
9. Follow board pattern
10. Segmental pattern
11. Shell pattern
12. Lagged up pattern.

1. Solid or Single piece pattern : Refer to Fig. 8.1.

- It is simplest of all the patterns and the cheapest.
- It is made in one piece and carries no joint, partition or loose pieces.
- Depending upon the shape, it can be moulded in one or two boxes.
- Its use can be made to a limited extent of production only since its moulding involves a large number of manual operations like gate cutting, providing runners and risers and the like.

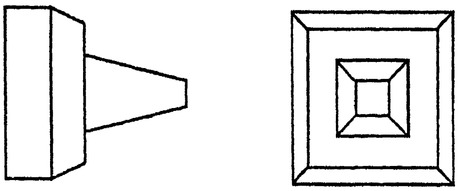
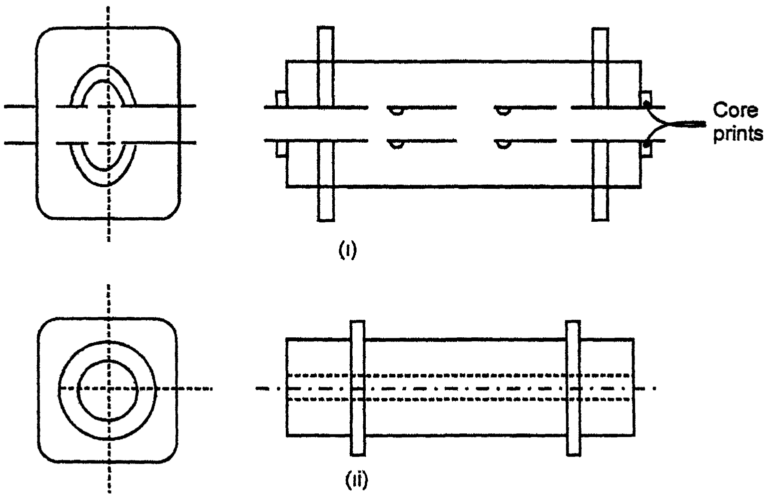


Fig. 8.1. Solid pattern.

2. Split pattern : Refer to Fig. 8.2.

- Most of the patterns are not made in a single piece because of the difficulties encountered in moulding them. In order to eliminate this difficulty, some patterns are made in two or more pieces.



(i) Two halves of pattern. (ii) Prepared casting
Fig. 8.2. A split pattern.

- A pattern consisting of two pieces is called a *two piece split pattern.* One-half of the pattern rests in the lower part of the moulding box known as *drag* and the other half in the upper part of the moulding box known as *cope.* The line of separation of the parts is called parting *line or parting surface.*

- Sometimes a pattern is constructed in three or more part for complicated castings. Such a pattern is called *multi-piece pattern* (Fig. 8.3).

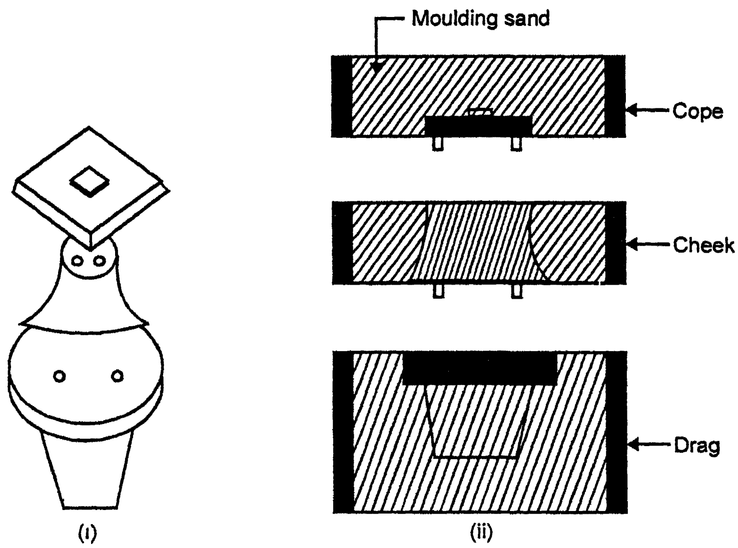


Fig. 8.3. Multipiece pattern.

3. Loose piece pattern : Refer to Fig. 8.4.

In some cases a pattern has to be made with projections or overhanging parts. These projections make the removal of the pattern difficult. Therefore such projections are made in loose pieces and are fastened loosely to the main pattern by means of wooden or wire dowel pins. These pins are taken out during moulding operation. After moulding the main pattern is withdrawn first and then the loose piece is removed by using a lifter.

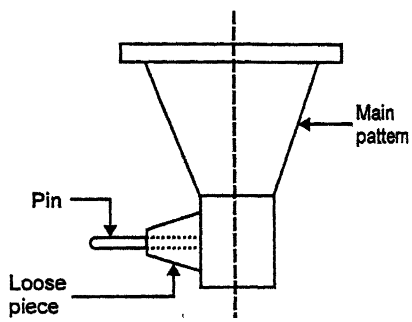


Fig. 8.4. Loose piece pattern.

4. Match plate pattern :

- A match plate pattern is made by fastening each half of a split pattern to the opposite side of one plate. The plate provides a substantial mounting for patterns and is *widely used in machine moulding.* The gates and runners are also attached in their correct position. On the drag side the plate is equipped with location holes which fit into the pins provided on the drag portion of the flask.

When the match plate is lifted off the mould all patterns are drawn, and the cope or upper half of the mould matches perfectly with the drag or lower half of the mould. *The gates and runners are also completed in the same operation.*

- Fig. 8.5 shows a match plate upon which the patterns of two small dumb bells are mounted.

- Match plate patterns are *expensive to construct* (but the initial cost is justified in mass production).
- These patterns are *suited for mass production of small castings in moulding machines.*

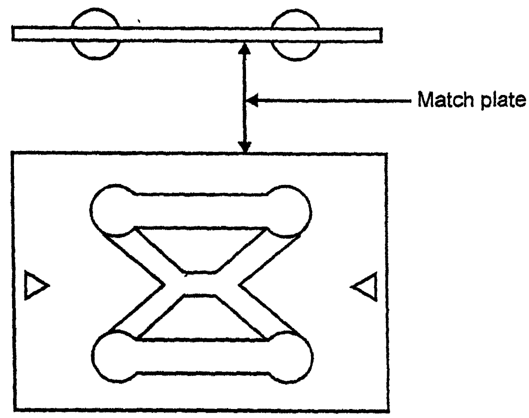


Fig. 8.5. Match plate pattern.

5. Gated pattern :

- In production where several small castings are required, gated patterns are used.
- Such patterns are made of metal to give them strength and to eliminate any warping tendency.
- To save time, a number of castings are produced in a single *multicavity mould by joining a group of patterns.* The gates or runners for the molten metal are formed by the connecting parts between the individual patterns. These groups of patterns with gate formers attached to them are called *gated patterns* (See Fig. 8.6).

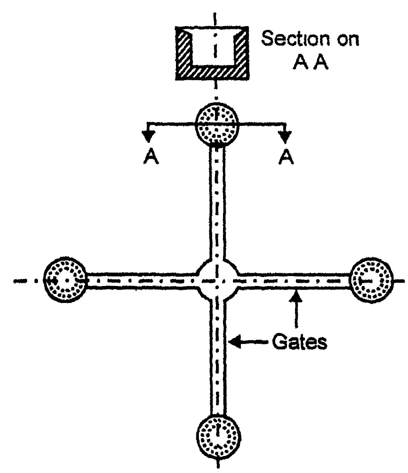


Fig. 8.6. Gated pattern.

6. Skeleton pattern : Refer to Fig. 8.7.

- When a fewer large castings are required, solid patterns would require a tremendous amount of timber, which may not be economical.

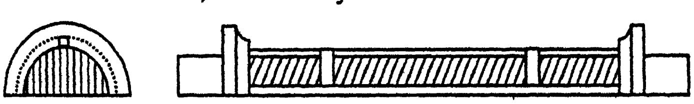


Fig. 8.7. A skeleton pattern for a flanged pipe.

In such cases the pattern is made of *wooden frame and rib construction* (skeleton) so that it will form a partially or interior outline of the casting and provide the general colour and size of the desired casting. The ribbed construction with a large number of square or rectangular openings between the ribs is filled and rammed with clay sand or foam. A strike off board known as *'strickle'* board is used to scrape the excess sand out of the spaces between the ribs so as to make the exterior surface even with the outside of the skeleton (See Fig. 8.7).

- Usually, skeleton pattern is built in two parts ; one for the cope and another for the drag.

7. Sweep pattern : Refer to Fig. 8.8.

- Such patterns are employed in making mould of *large*

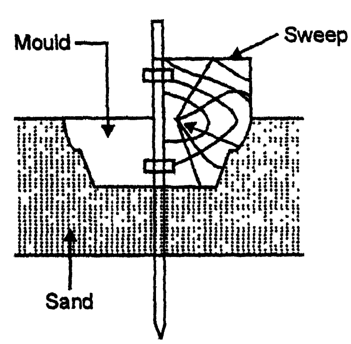


Fig. 8.8. Sweep pattern

symmetrical, circular cross-section to effect saving in time, labour and material.

- A *sweep* is a template of wood or other material which has contour corresponding to the shape and size of casting. It is *rotated about a central spindle* (See Fig. 8.8).

8. Cope and drag pattern :

When very large castings are to be made, the complete pattern becomes too heavy to be handled by a single operator. Such a pattern is made *in two parts which are separately moulded in different moulding boxes. After completion of the moulds, the two boxes are assembled to form the complete cavity, of which one part is contained by the drag and the other in cope.*

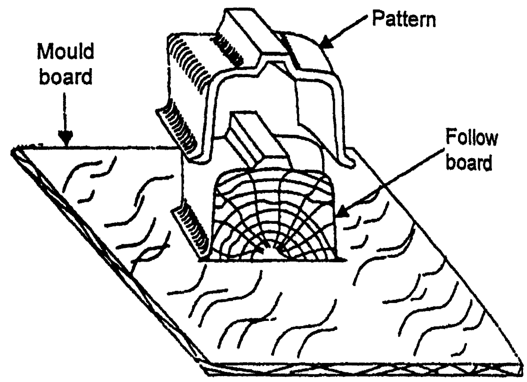


Fig. 8.9. A follow board pattern.

9. Follow board pattern :

The patterns having thin sections (See Fig. 8.9) tend to get distorted or collapse during ramming. Sagging of this pattern due to ramming can be easily overcome by constructing a supporting block (follow board) which may fit inside the pattern to serve as a support during ramming.

10. Segmental pattern : Refer to Fig. 8.10.

- These patterns are generally applied to circular work, like rings, wheels, rims, gears etc.
- In principle they work like a sweep, but the difference is that a sweep is given a continuous revolving motion to generate the desired shape whereas a *segmental pattern is a portion of the solid pattern itself and the mould is prepared in parts by it.* It is mounted on a central pivot (See Fig. 8.10) and after preparing the part mould in one position, the segment is moved to next position. The operation is repeated till the complete mould in ready.

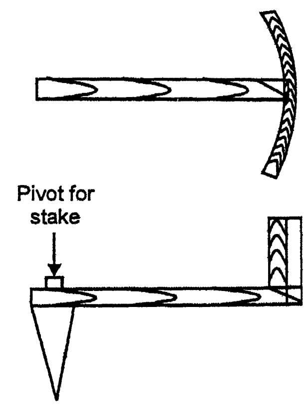


Fig. 8.10. Segmental pattern.

11. Shell pattern : Refer to Fig. 8.11.

- A shell pattern is largely used for *drainage fittings and pipe work.*
- This type of pattern is usually made of metal and parted along the centre line, the two sections being accurately dowelled together. The short bends are usually moulded and cast in pairs.
- The shell pattern is a hollow construction like a shell. *The outside shape is used as a pattern to make the mould, while the inside is used as a core box for making cores.*

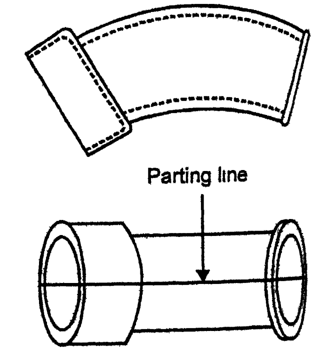


Fig. 8.11. Shell pattern.

12. Lagged-up pattern :

Refer to Fig. 8.12. Cylindrical patterns, *e.g.*, barrels, pipes or columns are built up with lag or stave construction to ensure proper shape. Longitudinal strips of wood, called *lags or staves* are bevelled on each side and glued to the wooden pieces called *'heads'* (See Fig. 8.12). Such a construction gives the maximum amount of strength and permits building close to the finished outline of the pattern so that there is comparatively little excess stock to be removed to bring it to the required form.

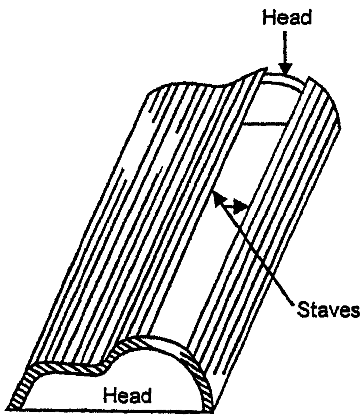


Fig. 8.12. Lagged-up pattern.

8.2.4. Pattern Allowances

While making patterns certain dimensional allowances must be given in the pattern so that the casting obtained is of the required specifications.

The following *allowances* are usually provided in a pattern :

1. Shrinkage allowance.
2. Draft or taper allowance
3. Machining allowance.
4. Rapping or shaking allowance.
5. Distortion allowance.

1. Shrinkage allowance :

- Shrinkage allowance is an allowance added to the pattern to *compensate for the metal shrinkage that takes place while the metal solidifies.* All metals except Bismuth and Gallium shrink.

The following table shows the contraction allowances for castings of different metals in sand moulds :

TABLE 8.1
Contraction Allowance for Different Metals

S. No.	*Metals / Alloys*	*Contraction allowance mm/metre*
1.	*Grey cast iron*	7 to 10.5
2.	*White cast iron*	21
3.	*Malleable iron*	15
4.	*Steel*	20
5.	*Copper*	16
6.	*Brass*	16
7.	*Bronze*	10.5 to 21
8.	*Zinc*	24
9.	*Lead*	24
10.	*Aluminium*	16
11.	*Magnesium*	18

Note. The contraction of metals/alloys is always *volumetric*, but the contraction allowances are always expressed in *linear measures*.

2. Draft or taper allowance :

- It is the taper provided on vertical surfaces of a pattern to *facilitate its removal from the mould without excessive rapping or breakage of cavity edges*. The amount of taper varies with the type of pattern.
- The taper on the inner surfaces should be greater than on the outside surface.
- The amount of taper varies from 0.5° to 1.5°. It may be reduced to less than 0.5° for larger castings.
- The wooden patterns require more taper than metal patterns because of the greater frictional resistance.

3. Machining allowance :

- Machining or finishing allowance is the *extra material provided on certain details of a casting so that the casting may be machined to exact dimensions.* The machining allowance depends on the following factors.
  (*i*) Casting process.
  (*ii*) Size of the casting.
  (*iii*) Degree of finish.
  (*iv*) Machining method.
  (*v*) Metallic alloy from which the casting is made.
- The amount of this allowance varies from 1.6 mm to 12.5 mm.
- The *ferrous metals require more machining allowance than non-ferrous metals.*

4. Rapping or shaking allowance :

- This allowance is provided to *compensate for enlargement of the mould cavity because of excessive rapping.*
- In small and medium-sized castings, this allowance can be neglected. But in larger casting this allowance is considered by making the part *slightly smaller than the casting* (*i.e.*, the allowance is a negative one as the pattern is made smaller to allow rapping operation).

5. Distortion allowance :

- This allowance is provided on the pattern *to compensate for possible distortion of the casting because of the unequal cooling rates of different sections of the casting and uneven internal stresses.*
- Such an allowance depends on the judgement and experience of the pattern maker, who understands the shrinkage characteristics of the metal.

8.3. MOULD MAKING

8.3.1. General Aspects

A **mould** *may be defined as the negative print of the part to be cast and is obtained by the pattern in the moulding sand container (boxes) into which molten metal is poured and allowed to solidify.* Sand moulds are destroyed as the casting is removed from the moulds.

Moulding is *an art of making sound mould out of sand by means of pattern and cores so that metal can be poured into the moulds to produce casting.*

— *Moulding is done both by hands and by machines.* Hand moulds are restored to *odd castings* generally less than 50 pieces at a time or so. Here ramming in done by hand which takes more time than machine moulding. However the quality is better for odd castings.

For mass manufacture, machine moulding is suitable. Moulding machines are prominently used in big foundries.

The **moulding machines** *perform the following basic operations :*

1. Ramming the sand in the mould,
2. Lifting or drawing of pattern from the mould, and
3. Rolling over mould section.

Following are the *two main classes of moulding machines :*

(*a*) *Hand moulding machines.*

(*b*) *Power moulding machines :*

(*i*) Jolt-machine.
(*ii*) Squeezing machine.
(*iii*) Jolt-squeeze machine.
(*iv*) Sand slinger.
(*v*) Diaphragm moulding machine.
(*vi*) Stripper-plate machine.

- Moulding is carried out in moulding boxes called *flasks,* which are open at the top and bottom; the top part is called the *cope* and the lower part as the *drag.* The

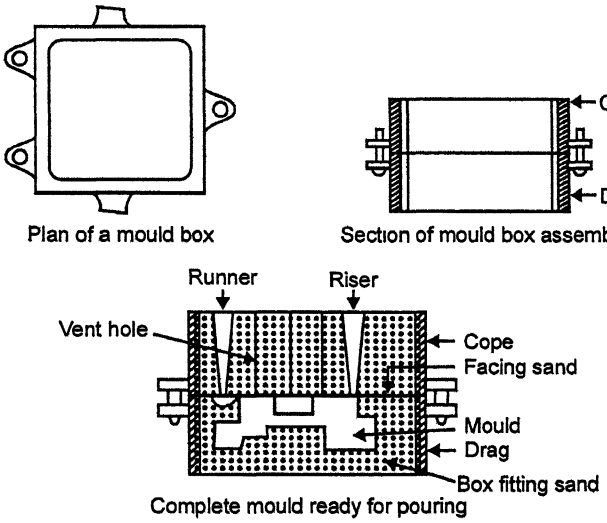


Fig. 8.13. Mould making.

moulding boxes are usually either of fabricated mild steel or cast iron which can be clamped together. To avoid misfitting of two halves there are two pins on one side

and one pin on other side in the top half which go into corresponding holes of the bottom half. This avoids the possible misfit. In case of very big castings, the moulds may be made on ground without moulding boxes. In some cases moulding boxes are put in 3 pieces (the intermediate part is called a *cheek*) to facilitate moulding. The section of moulding box is shown in Fig. 8.13.

8.3.2. Types of Moulds

The moulds are of the following two types :

1. Temporary moulds :

These moulds are destroyed at the time of removing castings from them.

Example : Sand moulds.

2. Permanent moulds :

These moulds are used in die casting. These moulds are used time and again.

Example : Metallic moulds.

8.3.3. Moulding Processes

The moulding processes may be *classified* as follows :

1. Bench moulding :

- The moulding done on a bench of convenient height to the moulder is called *bench moulding.*
- It is used for small work.

2. Floor moulding :

- The moulding done on the foundry floor is called *floor moulding.*
- It is used for all medium sized and large castings.

3. Pit moulding :

- Very large moulds made in a pit or cavity cut in the floor to accommodate very large castings is called *pit moulding*. The pit acts as a drag.
- Since pit moulds can resist pressures developed by hot gases, therefore, it greatly saves pattern expenses.

4. Machine moulding :

- The mouldings done by a machine is called *machine moulding.*
- Small, medium and large moulds may be made with the help of a variety of machines.
- Machine moulding is usually faster and more uniform than bench moulding.
- Machine moulding generally requires mounted patterns.

8.3.4. Types of Sand Moulding

Sand moulding methods may be *classified* as follows :

1. Green sand moulds.
2. Dry-sand moulds.
3. Skin-dried moulds.
4. Loam moulds.
5. Metal moulds.

1. Green sand moulding (moulds) :

Among the sand-casting processes, moulding is often done with green sand. *Green moulding sand* may be defined as a *plastic mixture of sand grains, clay, water, and other materials, which can be used for moulding and casting processes.* The sand is called *"green"* because of moisture present and is thus distinguished from dry sand.

The basic steps in green-sand moulding are as follows :

(*i*) ***Preparation of the pattern.*** Most green-sand moulding is done with match plate or cope and drag pattern. Loose patterns are used when relatively few castings of a type are to be made. In simple hand moulding the loose pattern is placed on a mould board and surrounded with a suitable-sized flask as illustrated in Figs. 8.14 and 8.15 respectively.

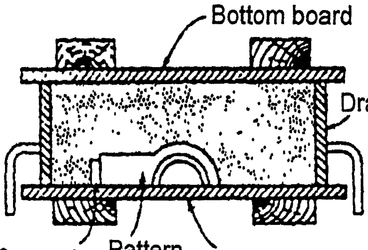


Fig. 8.14. Drag half of mould made by hand. Drag is ready to be rolled over in preparation for making the cope.

(*ii*) ***Making the mould.*** Moulding requires ramming of sand around the pattern. As the sand is packed, it develops strength and becomes rigid within the flask. Ramming may be done by hand, as in simple set up illustrated in Fig. 8.14. Both cope and drag are moulded in the same way, but the *cope must provide for the sprue.* The gating-system parts of the mould cavity are simply channels for the entry of the molten metal, and can be moulded as illustrated in Fig. 8.15.

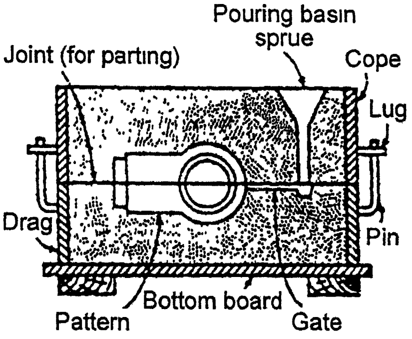


Fig. 8.15. Cope mould rammed up.

(*iii*) ***Core setting.*** With cope and drag halves of the mould made and the pattern withdrawn, cores are set into the mould cavity to *form the internal surfaces of the casting.*

(*iv*) ***Closing and weighing.*** With cores set, the cope and drag are closed. The cope must usually be weighted down or clamped to the drag to prevent it from floating when the metal is poured :

Advantages :

1. Great flexibility as a production process.
2. The least costly method of moulding.
3. Less time consuming since no backing operations or equipment is required.
4. Green sand moulds can be used for all types of the ferrous and non-ferrous alloys.

Disadvantages/Limitations :

1. Certain metals and some castings develop defects if poured into moulds containing moisture.

2. More intricate castings cannot be made.
3. The dimensional accuracy and surface finish of green-sand castings may not be adequate.
4. Green sand moulds are not very strong and may be damaged during handling or by metal corrosion.
5. Storage of green sand moulds for longer periods is not possible.

2. Dry-sand moulds :

- The sand mould made with a sand that does *not* require moisture to develop strength (the binder provides strength) are called *dry sand moulds.*
- These moulds are used for *steel castings.*
- The dry-sand moulds are stronger and may be handled more easily with less damage.
- Dry sand eliminates the possibilities of moisture related defects in casting.
- These are *more expensive* comparatively.

3. Skin-dried moulds :

- The sand moulds with a dry sand facing and a green sand backing are called *skin-dried moulds.*
- They can be employed for casting all ferrous and non-ferrous alloys.
- They are more commonly used for *large moulds.*
- As compared to dry-sand moulds they are less expensive to construct, but more expensive than green sand moulds.
- They are less stronger than dry-sand moulds.

4. Loam moulds :

- These moulds are made with loam sand (a mixture of sand and clay). The loam sand also contains fire clay or gainster.
- They are used for large work.
- A loam mould is constructed of porous bricks cemented together with loam mortar. The inside of the brick structure forms the rough contour of the casting and it is faced with a 6 to 12 mm layer of loam sand to give the required shape.
- A loam mould requires enough area and space, difficult to give proper contour and shape and is *suitable only for a single casting.*

5. Metal moulds :

- The metal moulds are permanent type of moulds. These are used in die casting where molten metal is introduced into the metallic mould cavity by means of pressure. Sometimes even gravitational force is sufficient to feed the metal into the mould cavity.
- These moulds are used *in the casting of low-melting temperature alloys.*

Advantages :

(*i*) Improved surface furnish.
(*ii*) Since the castings produced by metal moulds have a smooth finish, therefore much of the machine work is eliminated.
(*iii*) High production rate.

(iv) Thin sections can be cast.
(v) Castings produced are less defective.

Disadvantages :

(i) High cost of moulds and equipment.
(ii) For maintenance of moulds/equipment, special skill is required.

8.4. CORE

- A **core** *is a body made of refractory material (sand or metal, metal cores being less frequently used), which is set into the prepared mould before closing and pouring it, for forming the holes, recesses, projections, undercuts and internal cavities.*
- The cores are subject to much more severe thermal and mechanical effects than the moulds, because they are surrounded on all sides (except for the ends) by molten metal. Consequently core sands should meet more stringent requirements.
- *Refractiveness or thermal stability of core can be increased by giving a thin coating of graphite or similar material to the surface of the core.*

8.4.1. Core Making

- Cores are made in simple wooden, metallic or plastic core boxes. These core boxes are part of the pattern equipment for the castings. The complicated shapes may require support of sand or metal formers until these are baked.
- The *simple method of core making is similar to that of mould making.* The sand mixture is rammed into the core box with a wooden rammer. Sometimes the cores may need reinforcement with wire or nails in order to provide internal support so that they may not collapse while handling. The core-sand mixture is rammed by hand or pneumatic rammers. Venting and other necessary operations are performed during construction of the core.
- For *production work, machines are used for core makings* where core-sand mixture is rammed by *jolting, squeezing or blowing by means of suitable machines.* The most common core making machine is the *core blower.* Venting, reinforcing and other necessary operations are performed by hand during core construction.

Sometimes cores may be made by *extruding a core-sand mixture through a suitable die opening and called "**stock cores**"* which are of symmetrical cross-section.

The cores are removed from the core box placed in metal trays and are baked in an oven at a suitable temperature varying from 150°C to 400°C for the required duration of time. The source of heat may be the burning of gas, oil, coke, or electric heating.

8.4.2. Types of Cores

A *core is a specially designed shape employed to take the place of metal in a mould.*

The cores may be *classified* as follows :

I. According to the state of the core :

(i) Green sand cores
(ii) Dry sand cores

(*iii*) Oil sand cores
(*iv*) Loam cores
(*v*) Metal cores.

(*i*) **Green sand cores :**

- These are made from ordinary moulding sand, mixed with floor-sand, thoroughly vented and not too damp.
- They are restricted to *simple shapes,* reinforced with substantial core irons for handling, and *not dried before using.*

(*ii*) **Dry sand cores :**

- These cores consist of moulding sand with controlled conditions of such opening materials as horse manure, sawdust or chopped straw, blended together in a mill with either water, clay water, molasses or any other suitable binding agent. Ample core irons are used for strengthening.
- The interiors of large cores are filled with coke to facilitate venting, and to overcome contraction strains.
- They are baked until perfectly dry.

(*iii*) **Oil sand cores :**

- They consist chiefly of sea shore or other silica sands, to which has been added a binding medium ; a few typical binders being linseed oil, resin, molasses and cereal flour.
- All cores of this type are baked before handling.

(*iv*) **Loam cores :**

- Loam cores are perforated cast-iron or steel barrels on to which has been wound straw or a hayband and then coated with loam. The whole is then baked perfectly dry.

(*v*) **Metal cores :**

- These cores are usually made of steel (See Fig. 8.16) and are mostly used in the making of non-ferrous castings, acting as densers, and they also impart a fine finish.
- They are also used for the production of iron castings, they produce a *white hard skin.*

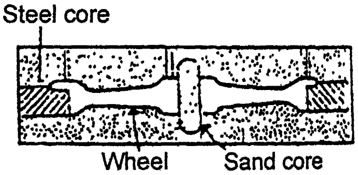


Fig. 8.16. Steel cores in a sand casting.

Note. Owing to contraction stresses, means should be provided whereby the cores can be released at a reasonable time after the metal in the casting has set.

II. According to the position of the core in the mould :

(*i*) Horizontal core (*ii*) Vertical core
(*iii*) Balanced core (*iv*) Cover core
(*v*) Hanging core (*vi*) Wing core.

(*i*) **Horizontal core :** Refer to Fig. 8.17 (*i*) :

- The core is usually cylindrical in form and is laid horizontally at the parting line of the mould.
- The ends of the core rest in the seats provided by the core prints on the pattern.

(*ii*) **Vertical core :** Refer to Fig. 8.17 (*ii*) :

- The core is placed vertically in the mould.
- Usually top and bottom of the core are provided with a taper, but the amount of taper on the top is greater than that at the bottom.

(*iii*) **Balanced core** : Refer to Fig. 8.17 (*iii*) :

- This core is similar to horizontal core, but it is supported at one end only.
- The core print in such cases should be large enough to give proper bearing to the core.

(*iv*), (*v*) **Cover core and hanging core** : Refer to Fig. 8.17 (*iv*) and (*v*) :

- The cover core, as shown in Fig. 8.17 (*iv*), is used when the entire pattern is rammed in the drag and the core is required to be supported from the top of the mould. This type of core usually requires a hole through the upper part to permit the metal to reach the mould.
- If the core hangs from the cope and does not have any support at the bottom in the drag, then it is called hanging core [Fig. 8.17 (*v*)].

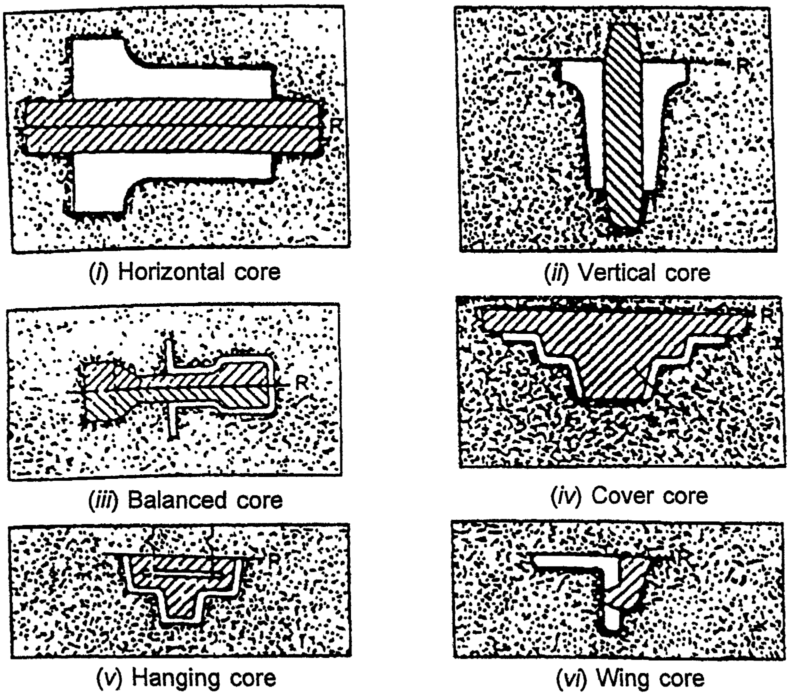


Fig. 8.17. Types of cores.

(*vi*) **Wing core** : Refer to Fig. 8.17 (*vi*) :

- A wing core is used when a hole or recess is to be obtained in casting either above or below the parting line. In this case, the side of the core point is given sufficient amount of taper so that the core can be placed readily in the mould.
- The core is sometimes designated by other names such as *tail core, drop core, chair core and saddle core* according to its shape and position in the mould.

Core sand :

- Core sand is a variety of silica sand. Rock sand, river sand and sea shore sand, commonly known as sharp sand, are generally used for making of cores, chiefly because they are *capable of withstanding high temperatures, and resisting the penetrating action of the molten metal. They have in addition, high porosity, together with good permeability.*
- Having no natural bond, these sands are mixed with a suitable binder of which there are several kinds in the form of creams, oils and resins. These binders are burnt out by the time the casting is cold making the core friable and easy to remove.

8.4.3. Core Prints

For supporting the cores in the mould cavity an impression in the form of a recess is made in the mould with the help of a projection on pattern. This projection is known as **core print.** Core prints are of the following types :

1. Horizontal core print

It produces seats for horizontal core in the mould.

2. Vertical core print :

It produces seats to support a vertical cure in the mould.

3. Balanced core print :

It produces a single seat on one aide of the mould and the core remains partly in this formed seat and partly in the mould cavities, the two portions balancing each other. The hanging portion of the core may be supported on chaplets.

4. Cover core print :

It forms seat to support a cover core.

5. Wing core print :

It is used to form a seat for a wing core.

8.4.4. Core box

- A core box is a *type of box used for the production of sand cores.* Core boxes are used in foundry work to form shapes in sand, called cores, which are used in connection with moulds, when *holes or internal shapes are required.*

Various methods of construction are used depending on the shape or size of the core, and its removal from the box after it is made. The inside of a core box must be cut out to form the exact shape of the hollow part required in the casting, plus the extensions for locating in the prints.

- The core boxes are filled with sand which is made firm with ramming and removed by opening the box at a centre joint, or taking it away from the core in various directions by a number of joints.
- If a plain hole is required in a casting, the core is a cylindrical piece of sand, the length of .the hole plus the print portion ; this core can be made in a **simple core box** cut from *two pieces of wood held together with dowels on the centre joint.* Fig. 8.18 (*i*).

- Another method of building up core boxes is to make the joints in such positions as will enable straight cuts to be made, *e.g.*, **piston core box**, Fig. 8.18 (*ii*). Each piece of the box is made to thickness of the sections at which the diameter of the piston alters, and screwed together. After making out of the joint on the box, the pieces are taken apart and cut through, glued and screwed back in position.
- **Stickles** *are frequently used with core boxes to obtain shapes of large works.* They work from a *guide held against a parallel side of the core box.* Fig. 8.18 (*iii*). A considerable amount of time in building up and shaping is saved by their use.

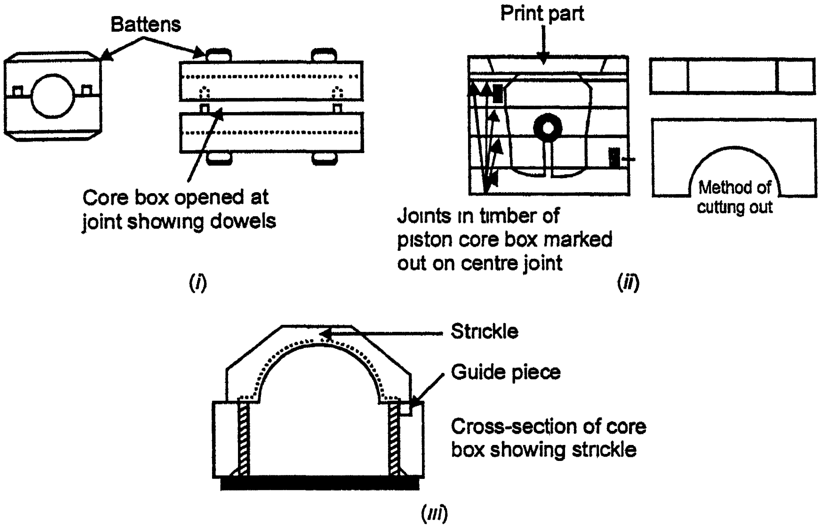


Fig. 8.18. ***Core boxes : (i) Simple box for cylindrical core, (ii) Piston core box, arranged for straight cuts ; (iii) Strickle used to shape large cores.***

8.5. MOULDING SAND

In a foundry shop sand is the principal moulding material and is used for all types of castings. The moulding sand possesses all the properties which are vital for foundry purpose and is used time and again.

8.5.1. Properties of Moulding Sand

1. Permeability :

- It is the property to allow gases to escape easily from the mould.
- Higher the silt content of sand, the lower is gas permeability. If the mould is rammed too hard, its permeability will decrease and vice versa.
- It is measured in number such as 60, 80, 100, 120 etc.

2. Strength or cohesiveness :

- It is defined as the *property of holding together of sand grains.*
- A moulding sand should have ample strength so that mould does not collapse or get partially destroyed during conveying, turning over or closing.

- The strength of the moulding sand *grows with density, clay content of the mix* and *decreased size of sand grains.* Thus as the *strength of the moulding sand increases, its porosity decreases.*

3. Refractiveness :

- *It is the ability of the moulding sand mixture to withstand the heat of melt without showing any sign of softening or fusion.*
- It *increases with the grain size of sand and its content and with the diminished amount of impurities and slit.*

4. Plasticity or flowability :

It should be of plastic nature so that it can easily take any desired shapes.

5. Collapsibility :

- *This is the ability of the moulding sand mixture to decrease in volume to some extent under the compressive forces developed by the shrinkage of metal during freezing and subsequent cooling.*
- This property permits the moulding sand to collapse easily during shake out and permits the core to collapse easily during its knock out from the cooled casting.
- Lack of collapsibility in the moulding sand and core may result in the formation of cracks in the casting.
- This property depends on the amount of quartz sand and binders and their type.

6. Adhesiveness :

- This is the property of sand mixture to *adhere* to another body.
- The moulding sand should cling to the sides of the moulding boxes so that it does not fall out when the flasks are lifted and turned over.
- This property depends on the type and amount of binder used in sand mix.

7. Coefficient of expansion :

The sand should have low co-efficient of expansion.

8. Chemical resistivity :

The sand should not chemically react or combine with molten metal.

8.5.2. Types of Moulding Sand

The moulding sands are *classified* as follows :

I. ***According to their clay bonding material :***

1. Natural sand : It contains sufficient amount of binding clay and, therefore, no more binder is required to be added.

2. Synthetic sand : It is one which is artificially compounded by mixing sand, and selected type of clay binders etc. These sands have the following *advantages* :

- Lower cost in large volume.
- Widespread availability.
- The possibility of sand reclamation and reuse.

II. ***According to their use :***

1. Green sand :

- The sand in its natural or moist state is called *green* sand.

- It is a mixture of silica sand with 20 to 30% clay, having total amount of water from 6 to 10%.
- The green sand moulds are used for small size castings of ferrous and non-ferrous metals.

2. Dry sand :

- When the moisture from the green sand is evaporated by drying or baking, after the mould is made is called *dry sand* mould.
- The dry sand moulds have greater strength, rigidity and thermal stability. The dry sand moulds are used for large and heavy castings.

3. Loam sand :

- The loam sand consists of as high as 50% of clay contents.
- It is used for loam moulding of *large grey-iron castings.*

4. Facing sand :

- A sand used for facing of the mould is called *facing sand.*
- Since it comes in contact with molten metal when poured, therefore it must possess high strength and refractiveness.

5. Parting sand :

- Parting sand is purely clay-free silica sand which is sprinkled on the pattern and the parting surfaces of the mould so that the sand mass of cope and drag separate without clinging and do not stick to the pattern.

6. Backing or flour sand :

- A sand used to back up the facing sand not used next to the pattern, is called *backing sand.*
- Because of its black colour, it is sometimes called *black sand.*

7. Core sand :

- A sand used for the preparation of the cores is called *core sand.*
- It is sometimes called *oil sand.*

8.5.3. Composition of the Green Sand

(*i*) Silica .... Up to 75 per cent
(*ii*) Clay .... 8 to 15 per cent
(*iii*) Bentonite .... 2 to 5 per cent
(*iv*) Coal dust .... 5 to 10 per cent
(*v*) Water .... 7 to 8 per cent

8.6. MELTING EQUIPMENT

The main types of furnaces used in foundries for melting various varieties of ferrous and non-ferrous metals and alloys are enumerated and described below :

1. Crucible furnace.
2. Reverberatory or air furnace.
3. Open hearth furnace.
4. Electric furnace.
5. Cupola furnace.

1. Crucible furnace : Refer to Fig. 8.19.

A crucible furnace is most suited for small foundries and can be designed for melting any of the metals. It consists of the following two main types :

(*i*) Pit type furnace.

(*ii*) Tilting type furnace.

(*a*) **Pit type crucible furnace :** Refer to Fig, 8.19 (*i*).

- It is built to suit the type of metal to be melted.
- These are fixed wholly or partly in the ground from which the crucible must be lifted when the metal is ready.
- Here a crucible (a heat resisting pot for metal melting and made of fire clay mixed with coke dust or graphite) is placed in a pit in the floor. The furnace is usually fired with sufficient coke being packed round and above the crucible pots to melt and superheat the charge without re-coking. The natural draught provided by tall chimney is controlled by means of loose brick or damper at the foot of the stack.

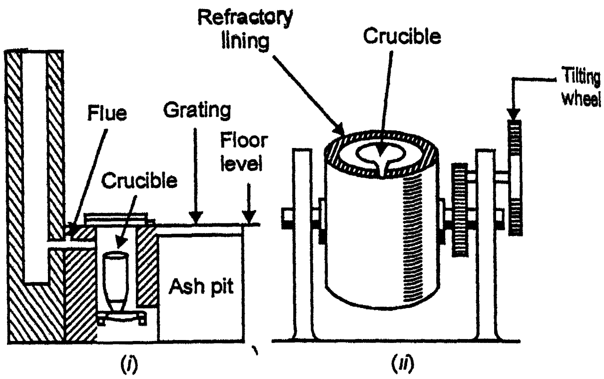


Fig. 8.19. Crucible furnace.

(*b*) **Tilting type crucible furnace :** Refer to Fig. 8.19 (*ii*) :

- This type of furnace is built above the ground level, and contains a firmly fixed crucible.
- The furnace is fired with coke, oil or gas and the forced draught is used.
- When the metal charge is ready for pouring, the whole furnace is tilted and the crucible emptied by operating a geared trunnion.
- For the metals of high melting points, clay or plumbago crucibles are used ; for the low-melting-point metals, such as zinc-base or aluminium, cast iron or steel cucibles are suitable.

2. Reverberatory or air furnace : Refer to Fig. 8.20.

- This is used for *melting in one*

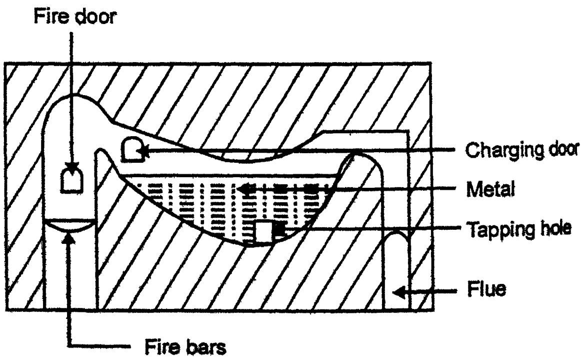


Fig. 8.20 Reverberatory or air furnace.

heat large quantities of metal, those most suited being all grades of cast-iron and the alloys of brasses and bronzes.

This type of furnace is also used for the production of wrought iron, and is then situated not in a foundry, but near forge or rolling mill, and is known as a *puddling furnace.*

- It may have either a sloping roof, or a double arched roof which forms a dip in the centre. A chimney is provided at one end and a fire grate or burners at the other end. A hearth or well is provided in the centre for holding the metal.
- It employs natural draught, which is controlled by dampers.
- The fuel can be either small lumpy coal, which is used on the fire grate, or powdered fuel, which is supplied through burners. The object is to create a long flame which reverberates or strikes back from the furnace roof on to the metal to be melted in the hearth.

3. Open hearth furnace : Refer to Fig. 8.21.

- An open hearth furnace is used chiefly for the *production of steel and for refining purposes.*
- Gas and heated air, admitted through the ports on the left, burn above the hearth. The hot, spent gases heat a brickwork chamber, before reaching the chimney stuck. After about twenty minutes the direction of air and gas flow is reversed, so that the cold air passes through the newly-heated brick chamber, while that on the left is reheated in preparation for the next cycle.

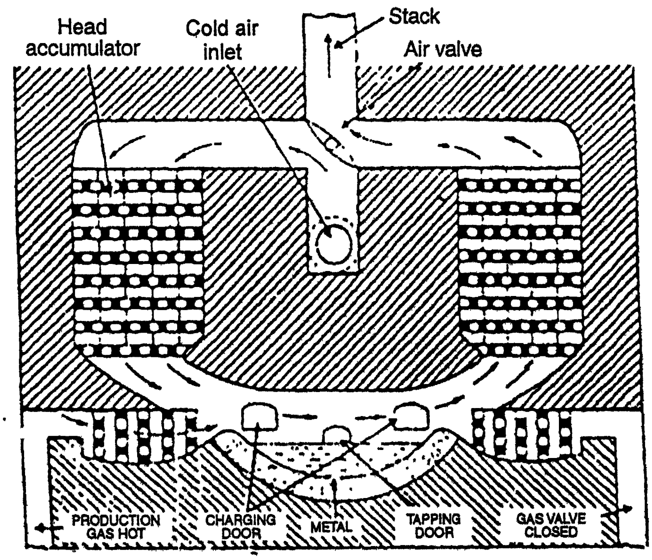


Fig. 8.21. Open hearth furnace.

4. Electric furnace :

This is used especially where rigid control over temperature and analysis is required. It is *suitable for all types of metals and alloys.*

The electric furnaces are classified as follows :

I. *Arc type furnaces :*

(*i*) Direct arc.

(*ii*) Indirect arc.

II. *Induction furnaces.*

I. ***Arc type furnace :***

(*i*) **Direct-arc furnace :** Refer to Fig. 8.22.

- It consists of a round, bowl-shaped carbon hearth with a domeshaped roof supporting one or more carbon electrodes through which passes the current which strikes arcs with the metal in the hearth, thus giving heat direct to the metal.
- This type of furnace can be either stationary or made to tilt. The roof is usually so made that it can be removed for charging purposes.
- The capacity of these furnaces for production work varies from 3 to 10 tonnes. These are best suited for laboratory work where very small quantity of a few kg is needed for research work.
- These furnaces give *high melting rate, high pouring temperature and excellent-control of metal analysis and temperature.*

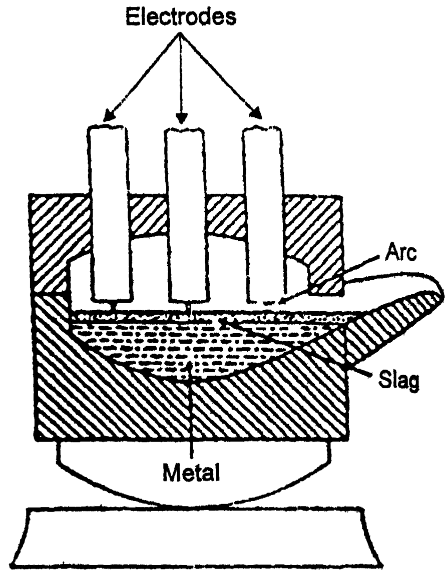


Fig. 8.22. Direct arc furnace.

(*ii*) **Indirect-arc furnace :**

- This furnace is used for melting *all types of metallic alloys but especially useful in the production of copper-base alloys.*
- It consists of a horizontal cylinder lined with a refractory material with two electrodes on the horizontal axis. An arc is struck between the electrodes in the centre of the furnace. The arc does not come in contact with the metal to be melted, the heat being given to the charge by radiation from the arc and reflection from the walls of the furnace. The furnace is designed to give a rocking motion as the melting proceeds, thus quickening up the melt by distributing the heat more rapidly. The charging, tapping and slagging are done through an opening in the side of the furnace.

II. ***Induction furnace :***

- An induction furnace is a tilting furnace used chiefly *for the melting of non-ferrous metals. Heat is generated by the resistance offered to an induced current set up within the metal in the furnace.*
- The design of the furnace is such that a small channel is formed inside at its base;

this channel in filled with metal, which should never be allowed to solidify owing to the amount of damage it would do to the lining.

- *When working, an alternating current is supplied to the primary coil of a transformer which is built with the furnace. This induces a current to pass through the liquid metal in the channel which acts as a secondary coil of the transformer. The forces set up by the current in the secondary circuit induce the metal in the channel to heat up and circulate through the bath of metal.*

5. Cupola furnace :

This furnace is mostly commonly used for *melting and refining pig iron* (alongwith cast iron and steel scarps) because of the following *reasons* :

(*i*) Simplicity of operation ;
(*ii*) Continuity of production ;
(*iii*) Economy of working ;
(*iv*) Increased output ;
(*v*) High degree of efficiency.

Construction and working : Refer to Fig. 8.23.

It is very similar to a blast-furnace in principle, *i.e.*, it is a vertical shaft furnace, into which the raw materials and fuel are charged at the top. Air for combustion of fuel is introduced through one or more rows of tuyeres a short distance above the bottom. *Since the cupola is only concerned with the melting of the metal and not with the reduction of ores as in the blast furnace, it is considerably smaller than a blast furnace of the same output.* Its diameter varies from 1 to 2 metres with a height of 4 to 5 times diameter.

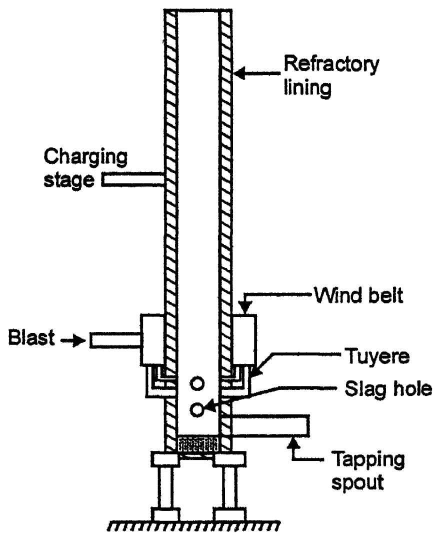


Fig. 8.23. Cupola.

- In a cupola, the first operation is to light the fire at the bottom. When the fire is burning strongly, coke is added gradually till the level above the tuyeres is about 0.6 metres. This coke serves as a bed for the alternate charges of metal and coke which follow. When the shaft of the cupola is filled level with the charging door the blast is put on and the combustion of the coke near the tuyeres increases rapidly until a very intense heat is attained. "The gases of combustion move upwards and pass on a portion of the heat to the metal and coke waiting to descend. In 5 to 10 minutes the first charge of metal starts melting and trickles down through the coke and finally collects at the bottom of the cupola. When an adequate quantity (say 1 or 2 tonnes) has accumulated the plug of clay called 'bout' is removed from the tap hole and metal allowed to run into the ladle. The temperature of tapping metal is 1200-1400°C. After melting a number of charges as per requirements the

bed coke is removed through a drop-bottom door and quenched with water so as to be available for use the next day.

- Although it is usual practice to operate a cupola with cold blast (since no reduction of ores is required) a few cupolas have been equipped for hot blast. It may be noted *whereas a blast furnace operates continuously, a cupola works intermittently.*

8.7. CASTING

- **Casting** *means the pouring of molten metal into a mould, where solidification occurs.*

Metal casting may also be *defined as a process of production of objects of desired shape and sizes by introduction of molten metal into a predesigned mould cavity created commonly in a compact sand mass, with the help of a pattern, or in a metallic mould (as in die casting) and allowing it to solidify.*

- Almost every finished metal product has been cast at some stage of its manufacture. For example, all rolled and forged steels are initially in the form of cast ingots, and even after extensive hot working, evidence of cast structure may still remain in the form of solids, chemical segregation, or surface defects.
- The main advantage of the foundry process is its *flexibility* and the *possibility of making all sorts and types of casting for a wide range of applications.*

8.8. ADVANTAGES AND DISADVANTAGES OF CASTING PROCESS

Advantages :

Casting process entails the following *advantages and disadvantages* :

1. *Cheapest* method of fabrication.
2. Objects of large size can be *produced easily.*
3. The objects having *complex and complicated shapes,* which cannot be produced by any other method of production, can usually be cast.
4. Castings with wide *range of properties* can be produced by adding various alloying elements.
5. By proper selection of type of moulding and casting process, *required dimensional accuracy in casting can be achieved.*
6. *Almost all the metals and alloys and some plastics can be cast.*
7. The number of castings can vary from *very few to several thousands.*

Disadvantages :

1. The *time* required for the process of making casting is *quite long.*
2. Metal casting involves melting of metal which is a high *energy consuming process.*
3. The *working conditions* in foundaries are *quite bad* due to heat, dust, fumes, slag etc., compared to other processes.
4. Metal casting is still *highly labou-intensive* compared to other processes.
5. The *productivity is less* than other automatic processes, *e.g.*, like rolling.

8.9. PREPARATION OF A CASTING

Preparation of a casting involves the following *steps* :

1. Preparation of a pattern.

2. Preparation of moulding sand.
3. Preparation of mould and core(s).
4. Melting the metal.
5. Pouring of metal into the mould.
6. Cooling and solidification.
7. Removing the casting from the mould.
8. Fettling (*i.e.*, cutting off the unwanted projection in the form of gates, risers etc.)
9. Heat treatment
10. Testing and inspection.

8.10. DESIGN OF A CASTING

As castings are produced by pouring hot metal into sand moulds at one time, the casting designer should consider the following *points* :

1. No section of a casting is less than 3 mm thick, as thinner sections are liable to break.
2. The joint between, the thinner and thicker sections is not suddenly changed in sections leading to stress concentration and ultimate weak sections.
3. As metal flows along smooth curves and does not flow in sharp corners, the smoothening of sharp edges by rounded fillets is necessary.
4. As cooling rates for thin sections is faster than those for thick surfaces care should be taken to see that the stress concentrations are not left in thin sections nor the metals (such as cast iron) get handened due to faster cooling.

8.11. CASTING PROCESSES

The various casting processes in use are *enumerated* and *described* below :

1. Sand casting.
2. Shell moulding.
3. Permanent mould casting.
4. Die casting.
5. Centrifugal casting.
6. Investment casting.
7. Plaster casting.
8. Slush casting.

1. Sand casting :

- A commonly used method involves pouring molten metal into a cavity in a mass of packed sand.
- Fig. 8.24 (*i*) shows a typical mould in cross-section. It illustrates the use of ***chills*** to produce a local hard surface, a ***core*** to form a shaft opening, and a ***sprue*** for running the molten metal into the cavity. A wood or metal ***pattern*** approximately the shape of the final casting is used to produce the cavity in the sand mould. So that the pattern may be removed from either the cope (upper) or the drag (lower) section of

the mould without disturbing the sand that has been packed around it, a taper or draft of a few degrees must be allowed on the metal faces of the pattern.

- Since casting alloys decrease in volume as they solidify and cool to room temperature, it is necessary to make the pattern larger than the final casting by an amount known as the shrinkage allowance. Shrinkage depends on such factors as the kind of alloy being cast, the design of the casting, the pouring temperature, and the size of the casting. In making castings such as those of a U-shape it is necessary to *"rake"* or distort the pattern in order to obtain the desired form in the final casting. This is called *distortion allowance.* An additional *machine finish allowance* of 1.6 mm or more must be allowed on surfaces that are to machined. Finally even with the use of the best available information on shrinkage allowance, it is unlikely that final dimensions of the casting can be corrected exactly. Therefore, size tolerance equal to half the shrinkage allowance are suggested for use with castings of new design.

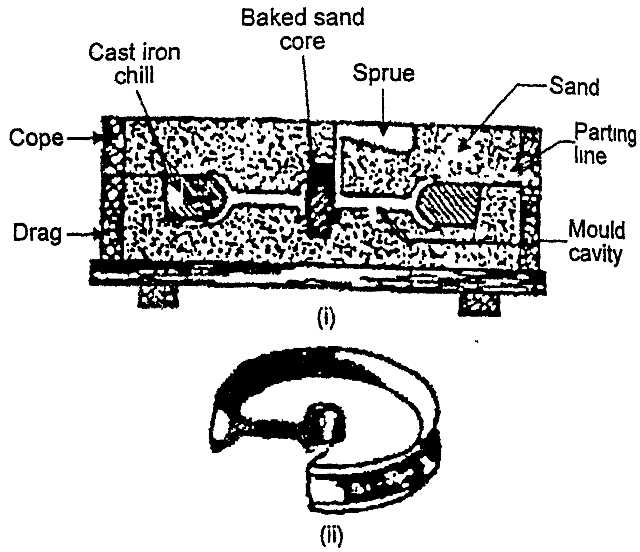


Fig. 8.24. (i) and (ii). Typical mould in cross-section.

Advantages :

(*i*) No limit on size and shape.
(*ii*) Almost any metal can be cast.
(*iii*) Low equipment cost.
(*iv*) Economical for low-volume production.
(*v*) Low production rate.
(*vi*) Extreme complexity possible.
(*vii*) Low tool cost.
(*viii*) Most direct route from pattern to casting.

Limitations :

(*i*) Product gives rough surface.
(*ii*) Dimensional accuracy difficult.
(*iii*) Thin projections not practical.
(*iv*) Machining always necessary.

2. Shell moulding :

- Shell moulding is modification of sand casting in which a *relatively thin shell forms the mould cavity* into which the molten metal is poured.
- Typically, each of the two halves of a shell moulding is *made by placing a mixture of fine sand and a resin binder in contact with a heated metal pattern.* Melting of the resin occurs in thin layer of the sand-resin mixture at the surface of the pattern, and this thin shell remains attached to the pattern when the excess mixture is allowed to fall off. The shell is then baked at a high temperature, removed from the pattern, and finally assembled with matching half to form the completed shell moulding.
- Castings produced by this process have *better surface finish and closer dimensional tolerances than sand castings.*

Advantages :

(*i*) A very smooth surface is generally obtained.
(*ii*) The shell cast parts can be produced with dimensional tolerance of ± 0.2 mm.
(*iii*) Reduced cleaning and machining costs.
(*iv*) Gives rapid production rate.
(*v*) Uniform grain structure.
(*vi*) Minimum finishing operations.

Disadvantages :

(*i*) The resin binder is more expensive than other binders.
(*ii*) The initial cost of metal patterns and other specialised equipment is high.
(*iii*) Dimensional limitations.
(*iv*) Limited to some specific metals.

3. Permanent mould casting :

- Permanent mould casting is a casting process in which *steel moulds and cores are employed.* When sand cores are employed with steel moulds, the process is called *semi-permanent mould casting.*
- The minimum number of castings for which it is economical to use permanent moulds is of the order of one thousand.

Advantages :

(*i*) The principal advantage of this casting method over sand casting is *economy.*
(*ii*) *Improved mechanical properties, close tolerances and better surface conditions.*
(*iii*) Rapid production.
(*iv*) Low scrap loss.
(*v*) Low porosity.
(*vi*) Very high mould life.

Disadvantages :

(*i*) High cost of mould.
(*ii*) Dimensional limitations.
(*iii*) Limited to low melting point metal castings.

4. Die casting :

- ***Die casting*** *is essentially permanent mould casting in which pressure forces the molten metal into the mould cavity.* However, the *mould used is much more expensive (it is called a "die") and a complex machine is employed to produce castings at a very high rate.*

  Fig. 8.25 shows the schematic arrangement of 'Die casting'.

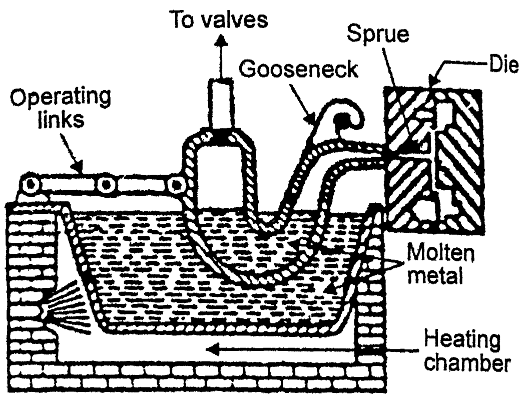


Fig. 8.25. Die casting.

Advantages :

(*i*) Large quantities of identical parts can be produced rapidly and economically.
(*ii*) Very little machining is required on the parts produced.
(*iii*) The parts having thin and complex shapes can be casted accurately and easily.
(*iv*) The die casting requires less floor area than is required by other casting processes.
(*v*) The castings produced by die-casting process are less defective, owing to increased casting soundness.
(*vi*) The rapid cooling rate produces high strength and quality in many alloys.

Disadvantages :

(*i*) The cost of equipment and die is high.
(*ii*) There is a limited range of non-ferrous alloys which can be used for die castings.
(*iii*) The die castings are limited in size. .
(*iv*) It requires special skill in maintenance.

5. Centrifugal casting :

- Castings that have rotational symmetry, such as long cylinders, are conveniently made by pouring the casting alloy into a metal, graphite or sand mould rotating above its axis of symmetry.

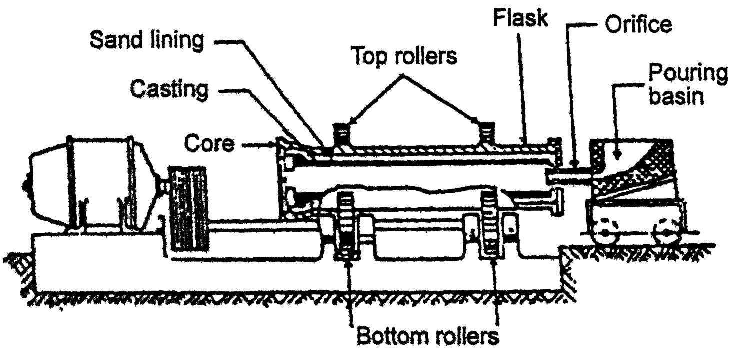


Fig. 8.26. Centrifugal casting.

- A machine for producing such centrifugal castings is shown in Fig. 8.26. Non-

metallic inclusions and slag particles, being less dense than the liquid metal, are forced to the inner surface of the casting and are removed in a later machining operation.

- *The mechanical properties of these castings are superior to those of sand castings, but gravity segregation is encountered in some alloys.*

Advantages :

(*i*) Quick and economical than other methods.

(*ii*) In this process the use of risers, feed heads, cores etc. is eliminated.

(*iii*) The ferrous as well as non-ferrous metals can be casted.

(*iv*) The castings produced have dense and find grained structure with all impurities forced back to the centre where they can be frequently machined out.

(*v*) Good surface finish.

(*vi*) Gates and risers can be kept to a minimum.

Disadvantages :

(*i*) Metallic composition of alloys is not uniform throughout the casting.

(*ii*) Casting must be symmetrical.

(*iii*) Limited to small intricate castings.

6. Investment casting :

- Investment costing is a process also known as the *"lost wax" process or "precision casting."* The term investment refers to a special covering apparel, in this case a refractory mould, surrounding a refractory-covered wax pattern.
- In this method, a wax pattern of the part to be made is embedded (invested) in a fluid ceramic material that subsequently becomes solid. This mould is heated, causing the wax to melt and flow out, leaving a cavity of the desired shape. Molten metal is poured into the mould cavity, and after the metal has solidified the mould material is broken away, leaving the final casting.
- Investment castings have *excellent surfaces* and *dimensional accuracy* and for this reason, they are used for parts made of *non-machinable and non-forgeable alloys. All extremely complex sections can be produced by this method, since there are no problems of draft, parting lines* and so on (as in sand casting).

Advantages :

(*i*) In average work the close tolerances (± 0.05 mm) are easily maintained.

(*ii*) Extremely smooth surfaces are produced.

(*iii*) Most machining operations including thread cutting and gear tooth forming are eliminated.

(*iv*) Adaptable to the metallic alloys.

Disadvantages :

(*i*) The large size objects are impractical for investment casting due to equipment size limits.

(*ii*) The investment moulds as well as the materials from which they are made are single purpose, therefore they can not be reused ; this increases the production cost.

7. Plaster casting :

If the sand-casting process is changed so that the Plaster of paris is substituted for sand as the moulding material the method is called *plaster casting*.

Advantages :

(*i*) High dimensional accuracy.
(*ii*) Smooth surface.
(*iii*) Low porosity.
(*iv*) Mould easily repairable.

Disadvantages :

(*i*) Limited to non-ferrous metallic castings.
(*ii*) Dimensional limitations.
(*iii*) Time consuming.

8. Slush casting :

Hollow castings, such as *statues*, can be made by pouring a low-melting point alloy into a bronze or a plaster mould and quickly pouring out the excess molten metal after a thin solid shell has formed. The resulting slush casting can be finished by *electroplating* and *lacquering*.

8.12. DEFECTS IN CASTINGS

A large number of defects occur in sand castings produced through various methods. The *factors* which are normally responsible for the *production of these defects are :*

- Design of casting.
- Design of pattern equipment.
- Moulding and core-making equipment.
- Mould and core materials.
- Gating and risering.
- Melting and core-making techniques.
- Melting and pouring.
- Composition of the metal.

Some of the common defects in casting are described below :

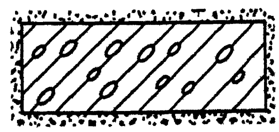


Fig. 8.27. Blow or gas holes.

1. Blow holes : Refer to Fig. 8.27.

- They appear as *cavities in a casting*. When they are visible on the upper surface of the casting, they are called *"open blows"*. When they are concealed in casting and are not visible from outside, they are known as ***blow holes***. They are due to the ***entrapped bubbles of gases*** in the metal and are exposed only after machining.
- They are caused mainly by *hard ramming, excessive moisture, low permeability, excessive fine grains and incomplete or improper venting*.

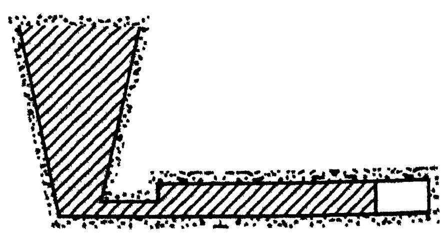


Fig. 8.28. Misrun.

2. Misrun : Refer to Fig 8.28.

- This defect is *incomplete cavity filling*.

- It is caused mainly by *inadequate* metal supply, too low mould or melt temperature and improperly designed gates.
- This defect determines the minimum thickness that can be cast for a given metal, superheat, and type of mould.

3. Cold shut : Refer to Fig. 8.29.

A *cold shut is an interface within a casting that is formed when two metal streams meet without complete fusion.* The causes are the same as for misrun.

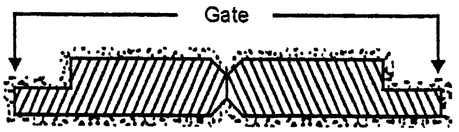


Fig. 8.29. Cold shut.

4. Mismatch : Refer to Fig. 8.30.

- It *is shift of the individual parts of a casting with respect to each other.*
- It is caused by an inexpert assembling of the two halves of the mould and dimensional discrepancy between the core prints of the pattern and the core prints of the core.

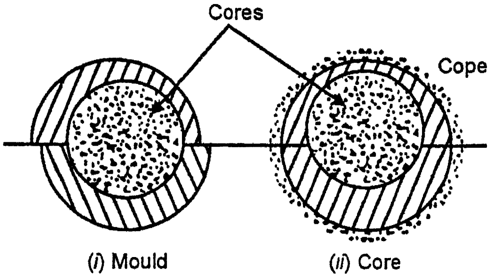


Fig. 8.30. Mismatch.

5. Drop : Refer to Fig. 8.31.

- This defect appears as a*n irregular deformation of a casting.*
- It occurs on account of a portion of the sand breaking away from the mould and dropping into the molten metal.
- *Increase in green strength of the sand by suitable modification in its composition, hard ramming and adequate reinforcing of cope and other sand projections by means of bars, nails and gaggers etc. are the principal remedies of this defect.*

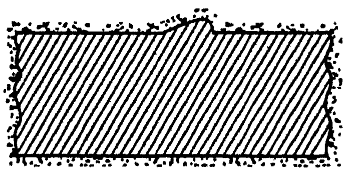


Fig. 8.31. Drop.

6. Flashes or fins :

- These are *thin projections of metal not intended as a part of casting.* These usually occur at the parting line of the mould or core sections.
- These are caused by loose clamping of the mould, insufficient weight on the top part of the mould and excessive rapping of the pattern before it is withdrawn from the mould.

7. Fusion :

- This defect appears as a rough glassy surface over the casting.
- It is caused due to lack of enough refractoriness in sand, faulty gating, too high pouring temperature of the metal and poor facing sand.

8. Metal penetration :

- This defects occurs as a *rough and uneven external surface on the casting.*
- The principal causes for the promotion of this defect are the use of coarse sand, having high permeability and low strength, and soft ramming.

9. Cut or wash : Refer to Fig. 8.32.

- It is a low projection on the drag face of a casting that extends along the surface, decreasing in height as it extends from one side of the casting to the other end.
- It usually occurs in bottom gating castings in which the moulding sand has insufficient hot strength, and when too much metal is made to flow through one gate into the mould cavity.

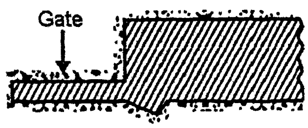


Fig. 8.32. Wash

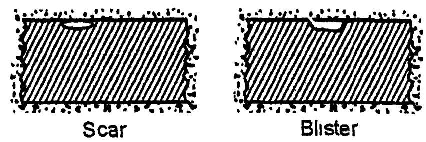


Fig. 8.33. Scar and blister.

10. Scars and blisters : Refer to Fig. 8.33.

- A *scar* is a shallow blow. It generally occurs on a flat surface, where as a blow occurs on a convex casting surface.
- A *blister* is a shallow blow like a scar with a thin layer of metal covering it.

11. Hot tears : Refer to Fig. 8.34.

- These are the cracks having *ragged edges due to tensile stresses during solidification.* It is due to the discontinuity in the metal casting resulting from hindered contraction, occurring just after the metal has solidified.

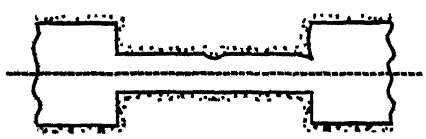


Fig. 8.34. Hot tears.

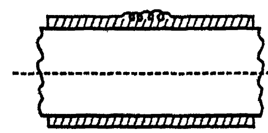


Fig. 8.35. Sponginess.

- This defect is caused by excessive mould hardness by ramming, high dry and hot strength and improper metallurgical and pouring temperature controls.

12. Sponginess : Refer to Fig. 8.35.

- Sponginess or honeycombing is an external defect, *consisting of a number of small cavities in close proximity.*
- It is caused by *'dirt'* or *'inclusions'* held mechanically in suspension in molten metal.

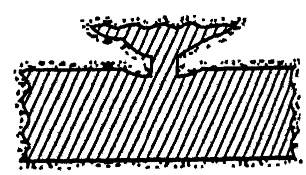


Fig. 8.36. Scab.

13. Scab : Refer to Fig. 8.36.

- This defect occurs when a portion of the face of a mould lifts or breaks down and the recess thus made is filled by metal.
- It is caused by too fine a sand, low permeability of sand and uneven ramming of the mould.

14. Swell : Refer to Fig. 8.37.

- A swell is a slight, smooth bulge usually found on vertical faces of castings, resulting from liquid metal pressure.

Fig. 8.37. Swell.

- It is caused due to low strength of mould because of too high water content or when the mould is not rammed sufficiently.

15. Buckle : Refer to Fig. 8.38.

- A buckle is a *long, fairly shallow, broad, vee depression that occurs in the surface of flat casting.*
- It occurs due to the sand expansion caused by the heat of the metal, when the sand has insufficient hot deformation. It is also caused due to poor casting design.

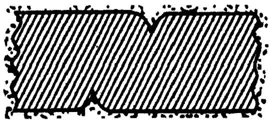


Fig. 8.38. Buckle.

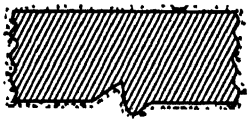


Fig. 8.39. Rat tail.

16. Rat tail : Refer to Fig. 8.39.

- A rat tail is a *long, shallow, angular depression in the surface of a flat casting and resembles a buckle except that it is not shaped like broad vee.* The reasons for this defect are the same as for buckle.

17. Slag holes :

- These are smooth depressions on the upper surfaces of the casting. These usually occur near the ingates.
- This defect is due to imperfect skimming of the metal or due to poor metal.

18. Pour short :

- It occurs when the mould cavity is incompletely filled because of insufficient metal.
- This defect occurs due to interruptions during pouring operation, and insufficient metal in the ladles being used to pour the mould.

8.13. CLEANING OF CASTINGS

Generally, the cleaning of casting refers to all operations related to the *removal of adhering sand, gates, risers or other metal not a part of the casting.* The cleaning operations may also include a certain amount of metal finishing or machining for obtaining the required casting dimensions.

The various cleaning operations usually performed on a casting are enumerated and discussed below :

1. Rough cleaning
2. Surface cleaning
3. Trimming
4. Finishing.

1. Rough cleaning. Rough cleaning includes the *removal of gates or risers.* The following points are worth-noting :

- In case of a ductile material casting, rough cleaning may be done with mechanical cut-off machines (using abrasive cut-off wheels, band saws and metal shears).
- The gating system of a brittle material casting may be broken off by impact when the castings are dumped and vibrated in shake-out or knock-out devices.

- In case of steel castings, very large risers and sprues way be removed by cutting torches.
- In case-of risers being large and cast of oxidation-resisting alloys, *powder cutting* (in which a stream of iron powder in introduced into the oxygen torch flame) is employed.

2. Surface cleaning. Surface cleaning includes cleaning of interior and exterior surfaces when sand, scale and other adhering materials are involved. This type of cleaning involves the following procedures :

(*i*) ***Tumbling***. This operation is carried out with a barrel-like machine called *tumbling mill*, which removes sand, scale and some fins and wires.

(*ii*) ***Blasting***. The *sand blasting* is performed by using coarse sand as abrasive and air as the carrying medium. The grit or sand blasting is carried out by throwing the metallic particles by centrifugal force from a rapidly rotating wheel.

(*iii*) ***Other surface cleaning methods :***

The following methods aid in surface cleaning :

— Wire brushing ;

— Buffing ;

— Pickling ;

— Various polishing procedures.

3. Trimming. Trimming involves the removal of fins, gate and riser pads, chaplets, wires and other similar *unwanted* appendages to the casting which are not a part of its final dimensions.

It involves the following *procedures :*

(*i*) ***Chipping.*** It is used to remove pins, gates and riser pads, wires etc. It may be carried out by hammer and chisel or by pneumatic chipping hammers.

(*ii*) ***Grinding.*** It is employed to remove excess metal and is carried out, through portable grinders, stand grinders and swing-frame grinders.

4. Finishing. It is the later stage of cleaning. In certain cases cleaning is complete after trimming operations, but others may require additional surface finishing, *e.g.*, machining, polishing, buffing etc.

8.14. INSPECTION OF CASTINGS

In order to determine the presence of any defects (not readily visible) it becomes necessary to inspect the casting. Following methods are employed to *inspect the casting.*

1. Destructive inspection method. In this type of inspection the casting sample is destroyed during inspection. This method is used to test mechanical properties, *e.g.*, tensile strength, hardness etc. These tests are performed on the test bars or pieces cut from the casting sample.

2. Non-destructive inspection method. Following are the various methods of non-destructive inspection :

(*i*) ***Visual inspection.*** The main aim of this type of inspection is to ensure that the outward appearance of the casting looks good. Through this inspection the defects like cracks, tears, run outs, swells etc. may be detected.

(*ii*) ***Dimensional inspection.*** The dimensional inspection may be carried out by surface

plates, height and depth gauges, and plug gauges etc. Through this inspection it can be ascertained whether certain details are within tolerances or not.

(*iii*) ***Pressure testing.*** It is employed to locate leaks in a casting or to check the overall strength of a casting in resistance to bursting under hydraulic pressure. It is carried out on tubes and pipes.

(*iv*) ***Radiographic inspection.*** This type of inspection is employed to inspect *internal defects of a casting*, by the use of X-ray or gamma ray technique.

(*v*) ***Magnetic particle inspection.*** This inspection method is employed on magnetic ferrous castings for detecting invisible surface or slightly subsurface defects.

(*vi*) ***Fluorescent penetrant.***

- This type of inspection is employed to find minute pores and cracks on the surface of castings that may be missed even under magnification.
- In this method a fluorescent penetrating oil mixed with whiting powder is applied to the casting surface by dipping, spraying or brushing. The cracks or other defects become visible after the surface has been wiped dry (the oil creeping out of cracks).

QUESTIONS WITH ANSWERS

Q. 8.1. What is a centrifugal casting ? For what type of jobs would you recommend this casting process ?

Ans. The centrifugal casting process is carried out in a permanent mould which is *rotated during the solidification of the casting.*

For producing a *"hollow part"* the axis of rotation is placed at the centre of the desired casting. The speed of rotation produces a centripetal acceleration which segregates less dense non-metallic inclusions near the centre of rotation.

"Solid parts" can be made by a variation of this process by placing the entire mould cavity *on outside of the axis of rotation.*

- The castings produced by this method are *very dense and are used for such critical parts as **cylinder liners** etc.*

Q. 8.2. Describe the need of investment casting. Explain the investment casting process.

Ans. Need of investment casting :

- Investment casting is used *when intricate shapes, good dimensional accuracy and a very good surface finish are required.*
- Investment casting is suitable for *high melting point alloys* as well as difficult to machine metals. It is also suitable for *processing small size castings having intricate shapes.*

Investment casting process :

The various ***steps*** in investment casting are as under :

1. Preparation of heat-disposable pattern, together with its gating system is done by injecting wax or thermoplastic into the die cavity.

2. A *'tree'* is prepared from number of such pattern fixed to a wax or plastic runner bar with a suitable ceramic cup to act as pouring basin.

3. The tree is then dipped into a ceramic slurry (containing silica flour in ethyl accetate). Sufficient fine silica sand is sprinkled on the tree dipped in ceramic slurry. This enables the formations of a self-supporting ceramic shell mould to be formed around the wax assembly.

4. The ceramic shell mould is then baked so that the wax melts and flows out leaving a precise mould cavity.

5. The shell is fired between 850°C and 1000°C to eliminate all the wax and give more strength to the mould.

6. The molten metal is poured into the mould while it is still hot and cluster of castings is obtained.

- These days, *lost wax process* is used for manufacturing larger objects like cylinder heads, crankshafts etc. In these processes *'styrofoam'* is used instead of wax.

Q. 8.3. Explain the solidification process in sand casting.

Ans. Refer to Fig. 8.40. For proper understanding of solidification mechanism and rate of heat loss from the material to the mould etc. it is necessary to predict how the casting will solidify which avoids casting defects such as seams, gas holes and hot tears etc.

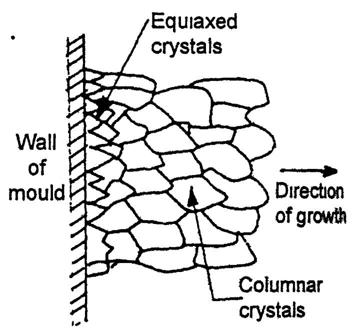


Fig. 8.40.

We know, solidification requireds energy to produce a crystalline structure, some supercooling (below freezing point) is required before the liquid metal starts solidifying. *This cooling is provided by the mould which provides sites around which crystals can grow initially and subsequently by the solidified particles, and the metal itself.*

In the case of casting, after pouring of the molten metal in the mould, the temperature falls steadily until freezing commences at a particular point. During solidification, the temperature more or less remains constant due to release of latent heat. In fact there may be a slight increase in temperature if supercooling has occurred. The temperature again starts falling steadily in case of pure metal. In the case of alloy, commencement of crystallization is followed by a period of less steep temperature reduction while the metal is passing through the mushy state.

Since an alloy does not have a sharply defined freezing temperature solidification takes place over a range of temperature. The solids separating out at different temperatures therefore possess different compositions. The direction of crystal growth is thus dependent upon the composition gradient within the casting variation of solids, temperature with composition and thermal gradient within the mould. The crystal growth in the case of alloys is of dendritic structure.

Q. 8.4. Discuss briefly the pouring temperature and pouring time in sand casting.

Ans. Pouring temperature. It is an important term and should be specified along with the casting method; accordingly tapping temperature and mould sequence determined.

Selection of pouring temperature is marked by the factors such as hot tearing and the lower limit by the ability of molten metal to flow in thin sections and avoidance of skulls in ladles. It also *influences metallographic structure, particularly grain size and structure.*

Pouring time. *It is the time to be taken in pouring the molten metal in sprue for casting.* It also plays an important role as this time is to be adjusted according to the requirement of a good casting.

If the liquid metal is poured very slowly, then the time taken to fill the mould is rather long and the mould has been completely filled up. On the other hand if the liquid impinges on the mould cavity with too high a velocity, the mould surface may be eroded.

Q. 8.5. What is Chvorinov's rule in casting and in what way it is useful ?

Ans. Chvorinov's rule for metal casting states the postulation that *total freezing (solidification) time for a casting is a function of the ratio of volume to surface area.*

$$\text{Solidification time} = C\left(\frac{\text{Volume}}{\text{Surface area}}\right)^2$$

where, C = A constant, that reflects mould material, metal properties like latent heat, and temperature.

- This *rule helps in determining the solidification time of casting. Accordingly we can select the method of casting.*

Q. 8.6. In what ways the "cooling curves" are useful in deciding the pouring temperature and pouring rate for sand casting ?

Ans. During cooling many characteristics such as crystal structure and alloy composition at different parts of the casting are decided. Unless a proper care is taken during cooling, defects like shrinkage, cavity, cold shut, misrun and hot tear occur. Due to all these reasons, the direction of crystal growth depends on the various factors such as :

(*i*) The variation of temperature with composition.

(*ii*) The thermal gradient within the mould.

(*iii*) Composition gradient within the casting.

The cooling patterns of an ordinary mould are shown in Fig. 8.41.

- *The cooling curves are useful to find out the too low pouring temperature which will cause partially filled cavities.* Also these are used to find *the too high pouring temperature which will create hard casting etc.*

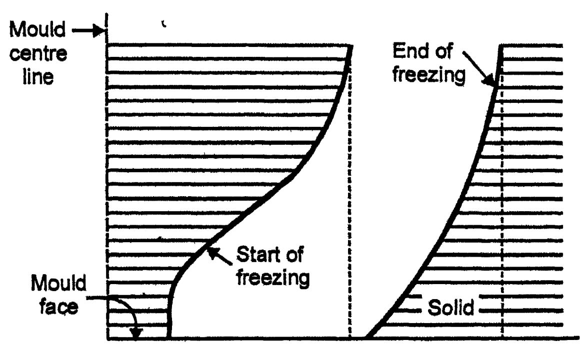


Fig. 8.41. The cooling patterns of an ordinary mould.

Q. 8.7. Discuss the role of moisture content (water percent) on the performance of sand casting moulds.

Ans. Moisture content affects the various properties of moulds as under :

1. It increases the permeability first and then in starts decreasing permeability when water content is more.

2. It increases the compressive strength first at faster rate and subsequently at slower rate.
3. It decreases the green strength.

Q. 8.8. Why risers are not used in die casting ?

Ans. Die castings are made by forcing molten metal at high pressures into a split steel die cavity. Within a fraction of second, the fluid alloy fills the entire die. The die is water cooled; therefore low temperature is being maintained. *Because of the low temperature of the die, the casting solidifies quickly.* Therefore *risers are not required in die casting.*

Q. 8.9. What purpose is served by risers in sand casting ?

Ans. Riser *is a hole cut or moulded in the cope to permit the molten metal to rise above the highest point in the casting.*

- Riser serves as feeder to feed the molten metal into the main casting cavity to *compensate for shrintage.* The design of the riser should be such that it establishes temperature gradients within casting so that the casting solidifies directionally towards the riser. It *also helps in easy ejection of steam, gas and air from the mould cavity while filling the mould with the molten metal.*
  Risers act as reservoir and heat gradient regulator and provide the necessary fluid metal to *compensate solidification.*
- *In case no riser is provided during casting the solidification will start from walls and liquid metal in the centre will be surrounded by a solidified shell and the contracting liquid will produce the voids towards the centre of casting.*

Q. 8.10. What are the causes of blow holes in castings and how they can be minimised during casting operations ?

Ans. Normally gases exist in a molecular form but at higher temperature and in contact with metal a significant portion of gases may dissociate in the atomic form and enter into the metal, these gases can be accommodated in the relatively loose and disordered structure of melts. This causes high solubility of gases above the melting point. *Solubility of gases falls steeply as the melt solidifies, some gas may be trapped in the solid in the atomic form but much is rejected at the solid liquid interface to combine into molecules.* These molecules come together and form a group into gas bubbles which rise in the melt or if trapped during solidification cause *gas porosity (pinholes or larger blow holes)* in the structure. These gas pores are generally round and if they contain a neutral or reducing gas, they have a clear, bright surface. They too can be regarded as inclusions of zero strength but their large radius makes them less damaging to mechanical properties. The *blow holes can also cause blistering.*

All the gases in all the metals are not equally soluble. Hydrogen is soluble in practically all metals because of small size of its atoms. Hydrogen may be introduced into the melt by dissociation of water from air, the charge or combustion products. In constrat to hydrogen, nitrogen is soluble in iron but not in non-ferrous metals. Noble gases (of which argon is technically most significant) are completely insoluble.

The solute S of any gas in melt increases or decreases with square root of the partial vapour pressure (p_g) of the gas over the melt (which is known as *Sivert's law*) and is given by:

$$S = K\sqrt{p_g}$$

where, K = The equilibrium constant.

It follows that the *concentration of any gas in the melt can be reduced by either reducing the overall pressure (by drawing a vacuum) or by bubbling a nonsoluble scavenging gas through the melt just before pouring.* Because the partial pressure of the offending gas is zero in the scavenging gas bubbles; the offending gas is drawn out of the solution into the rising scavenging gas and is removed.

Q. 8.11. Why casting is preferred over other methods of manufacturing ? Discuss.

Ans. Casting is preferred to other methods of manufacturing due to the following *reasons*:

1. High production rate.
2. Low process cost.
3. Intricate shapes can be obtained.
4. Cored holes, economy of material and metallurgical control is possible.
5. Process parameter can be well controlled.

Q. 8.12. Describe the pre-design consideration in the design of castings.

Ans. A product designer who selects casting as the primary manufacturing process should make a design not only to serve the function (by being capable of withstanding the loads and the environmental conditions to which it is going to be subjected during its service life) but also to facilitate or favour the casting process.

Following are some *design considerations and guidelines* :

1. ***Promote directional solidification.*** When designing the mould, the riser should be properly dimensioned and located to *promote solidification of the casting towards risers.* In other words the *presence of large sections or heat masses in locations distant from the risers should be avoided* and good rising practice should be followed. *Failure to do so may result in shrinkage cavities, porosity or cracks in those large sections distant from the risers.*

2. ***Avoid the shortcomings of columnar solidification.*** Dendrites often start to form on the cold surface of the mould and then grow to form a columnar casting structure.This almost always results in planes of weakness at sharp corners. Therefore *rounding of the edges is necessary to eliminate the development of planes of weakness.*

3. ***Avoid hot spots.*** The rate of solidification (and the rate of heat dissipation to start with) is slower at locations having a low ratio of surface area to volume. Such location are usually referred to as *hot spots* in the foundry practice. Unless precautions are taken during the design phase, hot spots and consequently shrinkage cavities are likely to occur at the L, T, V, Y and + junctions. Shrinkage cavities can be avoided by modifying the design. Also, it is *always advisable to avoid abrupt changes in sections and to use taper together with generous radii, to join thin to heavy section.*

4. ***Avoid the causes of hot tears.*** Hot tears in casting are defects caused by tensile stresses as a *result of restraining a part of the casting.* Efforts should be made to avoid the causes of hot tears.

5. ***Ensure easy pattern withdrawal.*** It is important that the pattern can be easily withdrawn from the mould. Undercuts, protruding bosses (especially if their axes do not fall within the parting plane) and the like should be avoided.

Q. 8.13. What is a continuous casting ?

Ans. The *"continuous casting process" consists of continuously pouring molten metal into a mould that has the facilities for rapidly chilling the metal to the point of solidification and then withdrawing it from the mould.*

- It has been proved through research and experimental work that there are many opportunities for cost economies in the continuous casting having a degree of soundness and uniformity not possessed by other methods of producing bars and billets.

Q. 8.14. Explain briefly 'slush casting'.

Ans.
- Slush casting generally *involves the process of low-temperature-melting alloys.*
- In this process hollow castings can be produced without the use of cores. The *principle involves pouring the molten metal into a permanent mould. After the skin has frozen, the mould is turned upside down or slung to remove the metal still liquid. A thin-walled casting results, the thickness depending on the chilling effect from the mould and the time of operation. Toys and ornaments* are made by this process from zinc, lead or tin alloys.

Q. 8.15. List the advantages claimed by permanent mould casting over sand casting.

Ans. The *permanent mould casting claims the following advantages over sand casting* ;

1. Smoother surfaces.
2. Freedom from gas porosity
3. Freedom from sand and dirt.
4. Rapid rate of production.
5. Low cost of unskilled labour needed.
6. Closer tolerance.
7. Free from internal shrinks.
8. High percentage of good castings.

Q. 8.16. (a) What is a 'gating system' ?

(b) What are the design requirements of the gating system ?

Ans. (a) Gating system. *The passage way in the mould meant for carrying molten metal to the mould cavity is known as gatting system.*

Fig. 8.42. shows an ordinary gating system.

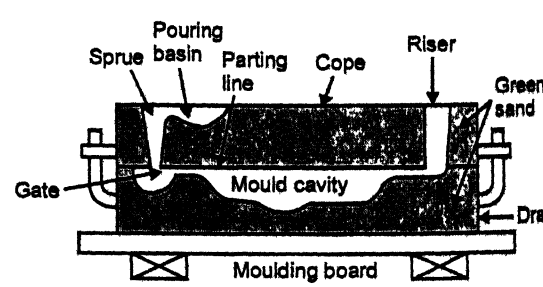


Fig. 8.42. Ordinary gating system.

(b) Design requirements of the gating system. Any gating system should *aim at providing* a *defect free casting*. This can be achieved by making provision for certain requirements while designing the gating system. These are as follows :

(i) The metal should flow smoothly into the mould without any turbulence.

(*ii*) The mould should be completely filled in the smallest time possible without having to raise metal temperatures nor use higher metal heads.

(*iii*) The gating system should ensure that enough molten metal reaches the mould cavity.

(*iv*) The metal entry into the mould cavity should be properly controlled in such a way that aspiration of the atmospheric air is prevented.

(*v*) The metal flow should be maintained in such a way that no gating or mould erosion takes place.

(*vii*) Unwanted material such as slag, dross and other mould material should not be allowed to enter the mould cavity.

(*vii*) A proper thermal gradient be maintained so that the casting is cooled without any shrinkage of cavities or distortions.

(*viii*) The design of the gating should be economical and easy to implement and remove after casting solidification.

Q. 8.17. Define the following terms :

(*i*) Sprue, (*ii*) Gate; (*iii*) Swell; (*iv*) Warpage; (*v*) Gravity segregation.

Ans. 1. Sprue. *The vertical passageway through which the molten metal flows down from a parting plane is called the* ***sprue.***

- It is connected to the mould in cavity by a gate or series of gates.
- The solidified metal that occupies the sprue passage after the mould has been poured, is known as *sprue of the casting.*
- The function of the sprue is to provide an entrance to mould cavity for the molten metal. Sprues may be designed with either a positive taper, a reverse taper a no taper at all (See Fig. 8.43).

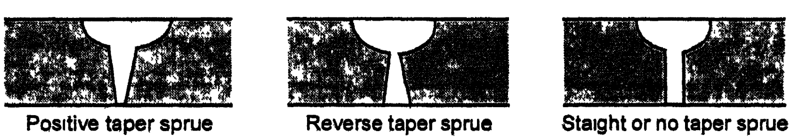


Fig. 8.43. Sprue designs.

2. Gate. *The opening or channel in the mould connected with the sprue, through which the molten metal flows into the mould cavity, is known as a* ***gate.***

If there is more than one cavity in the mould, the common gate supplying a number of cavities is called a *'runner'.*

3. Swell. A swell is an enlargement of the mould cavity by metal pressure, resulting in localised of the casting.

4. Warpage. This is unintentional and undesirable deformation in casting that occurs during or after solidification.

5. Gravity segregation. Aluminium engine blocks utilise centrifugally cast iron liners. In centrifugal casting if a metal can be melted, it can be cast centrifugally but for a few alloys the heavier elements *tend to be separated from the base metal.*

Q. 8.18. Explain briefly the following ;

(*i*) True centrifugal casting;

(ii) Semi-centrifugal casting;

(iii) Centrifugal casting;

Ans. 1. True centrifugal casting. In this process the metal is held against the wall of the mould by centrifugal force, and *no core is required to form a cylindrical cavity on the inside.*

True centrifugal casting is used for *pipes, liners* and *symmetrical objects* that *are cast by rotating the mould about its horizontal or vertical axis.*

Vertical castings are much smaller in size and weight because of the instability of a spinning vertical cylinder.

2. Semi-centrifugal casting. In this type of casting, the mould is completely free of metal as it is spun about its vertical axis, and *riser and cores may be employed.* The centre of the casting is usually solid, but *because the pressure is less there, the structure is not so dense and inclusions and entrapped air are often present.*

Rotational speeds for this form of centrifugal casting are *not so great as for the true centrifugal process.*

- This method is *normally used for parts in which the centre of the casting will be removed by machining.*

3. Centrifugal casting. In this case, several casting cavities are located around the outer portion of a mould, and metal is fed to these cavities by radial gates from the centre, Either single or stack can be used. The mould cavities are filled under pressure from the centrifugal force of the metal as the mould is rotated.

- The centrifuge method, *not limited to symmetrical objects,* can produce castings of irregular shape such as *bearing caps or small brackets.* The *dental profession uses this process for casting gold inlays.*

Q. 8.19. Explain very briefly the following casting processes :

(i) Electroslag casting; (ii) Precision casting; (iii) Pressed casting.

Ans. 1. Electroslag casting. This process is unusual in that it does not employ a furnace. Instead, consumable electrodes melting or striking beneath a slag layer furnish molten metal to fill a water-cooled permanent mould.

2. Precision casting. It employs techniques that enable very smooth, highly accurate castings to be made from both ferrous and non-ferrous alloys.

3. Pressed casting. This method of casting resembles both the gravity and slush processes but differs somewhat in procedure. This is also called *corthias casting.*

Q. 8.20. What are chills ?

Ans.
- **Chills** *are provided in the mould so as to increase the heat extraction capability of the sand mould.* A *chill provides a steeper temperature gradient so that directinal solidification as required in a casting be obtained.*
- The *chills are metallic objects having a higher heat absorbing capability than the sand mould.* These can be of two types :
  - (i) External chills (placed in the mould cavity adjoining the mould cavity at any required position).
  - (ii) Internal chills (placed inside the mould cavity where an external chill cannot be provided).

HIGHLIGHTS

1. *Casting* is perhaps the oldest method of manufacturing and invariably the first step in the sequence of manufacturing a product.
2. The *basic features* common to various casting process are :
   (*i*) Pattern and mould.
   (*ii*) Melting and pouring.
   (*iii*) Solidification and cooling.
   (*iv*) Removal, cleaning, finishing and inspection.
3. A *pattern* is defined as a model of a casting, constructed in such a way that it can be used for forming an impression (mould) in damp sand.
4. The following *allowances* are usually provided in a pattern :
   (*i*) Shrinkage allowance.
   (*ii*) Draft or taper allowance.
   (*iii*) Machining allowance.
   (*iv*) Rapping or shaping allowance.
   (*v*) Distortion allowance.
5. A *mould* may be defined as the negative print of the part to be cast and is obtained by the pattern in the moulding sand container (boxes) into which molten metal is poured and allowed to solidify.
6. *Sand moulding methods* may be classified as follows :
   (*i*) Green sand moulds
   (*ii*) Dry sand moulds
   (*iii*) Skin-dried moulds
   (*iv*) Loam moulds
   (*v*) Metal moulds.
7. A *core* is a specially designed shape employed to take the place of metal in a mould.
8. *Casting* means the pouring of molten metal into a mould, where solidification occurs.
9. The various casting processes are :
   (*i*) Sand casting
   (*ii*) Shell moulding
   (*iii*) Permanent mould casting
   (*iv*) Die casting
   (*v*) Centrifugal casting
   (*vi*) Investment casting
   (*vii*) Plaster casting
   (*viii*) Slush casting.

OBJECTIVE TYPE QUESTIONS

Fill in the blanks or say 'Yes' or 'No' :

1. .... is perhaps the oldest method of manufacturing and invariably the first step in sequence of manufacturing a product.

2. A .... is defined as a model of casting, constructed in such a way that it can be used for forming an impression (mould) in damp sand.
3. A pattern consisting of two pieces is called a two piece :................ pattern.
4. Match plate patterns are suited for mass production of small castings in moulding machines.
5. .... patterns are generally applied to circular work, like rings, wheels, rims, gears etc.
6. The constraction of metals/alloys is always .... , but the contraction allowances are always expressed in .... measures.
7. .... allowance is the extra material provided on certain details of a casting so that the casting may be machined to exact dimensions.
8. .... allowance is provided to compensate for enlargement of mould cavity because of excessive rapping.
9. For manufacture .... moulding is suitable.
10. Moulding is carried out in moulding boxes called ....
11. Sand mould is an example of permanent mould.
12. Bench moulding is used for large castings.
13. In pit moulding, the pit acts a drag.
14. .... moulds are used in the casting of low-melting temperature alloys.
15. A .... is a specially designed shape employed to take the place of metal in a mould.
16. A core box is a type of box used for production of sand cores.
17. Stickles are frequently used with core boxes to obtain shapes of large works.
18. An open hearth furnace is used chiefly for the production of steel and for refinning purposes.
19. .... means the pouring of molten metal into a mould, where solidification occurs.
20. Permanent mould casting is a casting process in which .... moulds and .... are employed.
21. Investment casting is a process also known as the lost wax process or precision casting.
22. A .... is an interface within a casting that is formed when two metal streams meet without complete fusion.
23. Mismatch is shift of the individual parts of a casting with respect to each other.
24. A scar is a shallow blow.
25. .... are the cracks having ragged edges due to tensile stresses during solidification.
26. .... defect occurs when a portion of the face of a mould lifts or breaks down and the recess thus made is filled by metal.
27. Rough cleaning of castings does not include the removal of gates or risers.

ANSWERS

1. Casting	**2.** pattern	**3.** split
4. Yes	**5.** Segmental	**6.** volumetric, linear
7. Machining	**8.** Rapping	**9.** machine
10. flasks	**11.** No	**12.** No
13. Yes	**14.** Metal	**15.** core
16. Yes	**17.** Yes	**18.** Yes
19. Casting	**20.** steel, cores	**21.** Yes
22. cold shut	**23.** Yes	**24.** Yes
25. Hot tears	**26.** Scab	**27.** No

THEORETICAL QUESTIONS

1. Define the term casting.
2. Why casting is preferred over other methods of manufacturing ? Discuss.
3. What are the basic features common to various casting processes ?
4. What is a pattern ?
5. Discuss briefly various pattern materials.
6. List the factors on which the types of patterns depend.
7. Enumerate the various types of commonly used patterns.
8. Explain briefly with neat sketches any *three* of the following patterns :
   (*i*) Solid pattern (*ii*) Loose piece pattern
   (*iii*) Skeleton pattern (*iv*) Segmental pattern
   (*v*) Cope and drag pattern (*vi*) Sweep pattern.
9. List the various types of allowances which are usually provided in a pattern.
10. Explain briefly the following pattern allowances :
    (*i*) Shrinkage allowance (*ii*) Machining allowance
    (*iii*) Rapping or shaking allowance (*iv*) Distortion allowance.
11. Define the following terms :
    (*i*) Mould; (*ii*) Moulding.
12. Name the basic operations which are performed on the moulding machines.
13. What are the two main classes of moulding machines ?
14. Explain briefly with neat sketches the 'mould making' process.
15. What is the difference between a 'temporary mould' and a 'permanent mould' ?
16. How are moulding processes classified ?
17. Explain briefly the following moulding processes :
    (*i*) Floor moulding.
    (*ii*) Machine moulding.
18. How are sand moulding methods classified ?
19. Explain briefly any two of the following moulding methods :
    (*i*) Green sand moulding (moulds) (*ii*) Dry-sand moulds
    (*iii*) Loam moulds (*iv*) Metal moulds.
20. What are the advantages and limitations of green sand moulding ?
21. What is a core ? How are 'cores' made ?

22. How are cores classified ?
23. Explain briefly any two of the following cores :
    (*i*) Green sand cores (*ii*) Dry sand cores
    (*iii*) Oil sand cores (*iv*) Loam cores
    (*v*) Metal cores
24. What are core prints ?
25. What is a core box ? Explain with a neat sketch.
26. Explain briefly the following properties of moulding sand :
    (*i*) Permeability (*ii*) Strength or cohesiveness
    (*iii*) Refractoriness (*iv*) Plasticity or flowability
    (*v*) Collapsibility (*vi*) Adhesiveness
    (*vii*) Coefficient of expansion (*viii*) Chemical resistivity.
27. How are moulding sands classified ?
28. Give the composition of the green sand.
29. Name the main type of furnaces used in foundaries for melting various varieties of ferrous and non-ferrous metals and alloys.
30. Explain briefly any two of the furnaces :
    (*i*) Crucible furnace (*ii*) Reverberatory or air furnace
    (*iii*) Open hearth furnace (*iv*) Electric furnace
    (*v*) Cupola furnace.
31. What do you mean by the term 'casting' ?
32. What are the advantages and disadvantages of casting processes ?
33. What steps are involved in the preparation of a casting ?
34. What points should the casting designer consider while designing a casting ?
35. Name the various casting processes in use.
36. Explain briefly the following casting processes :
    (*i*) Centrifugal casting (*ii*) Die casting
    (*iii*) Investment casting (*iv*) Slush casting.
37. State the advantages and limitations of sand casting.
38. Discuss permanent mould casting, stating its advantages and disadvantages.
39. Explain with a neat sketch die casting. State its advantages and disadvantages.
40. What is plaster casting ? What are its advantages and disadvantages ?
41. What are the factors which are normally responsible for the production of defects in castings.
42. Name the common defects found in castings.
43. Explain briefly the following defects in casting :
    (*i*) Blow holes (*ii*) Misrun
    (*iii*) Cold shut (*iv*) Mismatch
    (*v*) Fins (*vi*) Hot tear
    (*vii*) Scab (*viii*) Swell.
44. Explain briefly the following cleaning operations usually performed on a casting :
    (*i*) Rough cleaning (*ii*) Surface cleaning
    (*iii*) Trimming (*iv*) Finishing.
45. Discuss briefly the various methods employed to inspect the castings

□□

9

Fundamentals of Metal Forming

9.1. INTRODUCTION

The materials which are covered under the scope of material science are available either from nature or industry. However these materials cannot be used in raw form (whatever the source may be) for useful purposes. They have to be shaped and formed into articles through difference manufacturing processes. Besides there are some processes which improve material properties. In some processes the materials are changed into their primary forms for some selected parts. In some cases the materials are suitably finished for commercial uses. In other cases, neither surface finish nor the dimensions are satisfactory for the final product, and further work is necessary. However, the selection of the best process for a given product requires a knowledge of all possible production methods.

Some important processes are listed below :

1. Cold working :

(*i*) Drawing
(*ii*) Squeezing
(*iii*) Bending
(*iv*) Shearing
(*v*) Hobbing
(*vi*) Shot peening
(*vii*) Cold extruding.

2. Hot working :

(*i*) Rolling
(*ii*) Forging
(*iii*) Pipe welding
(*iv*) Hot piercing
(*v*) Hot drawing
(*vi*) Hot spinning
(*vii*) Hot extruding.

3. Forging :

(*i*) Hand forging
(*ii*) Machine forging.

4. Casting :

(*i*) Sand casting
(*ii*) Shell moulding
(*iii*) Permanent mould casting
(*iv*) Die casting
(*v*) Centrifugal casting
(*vi*) Investment casting
(*vii*) Plaster casting
(*viii*) Slush casting.

9.2. COLD AND HOT WORKING

9.2.1. Cold Working

A metal is said to be **cold worked**, *if it is mechanically processed below the recrystallization temperature of the metal.*

- Cold working produces an *improved surface finish and closer dimensional tolerance* and because of this characteristic cold working processes are generally used in making end-use products.
- Since recrystallization does *not* take place in cold working, the grains are *permanently distorted.*
- *During cold working residual stresses are set up. As their presence is undesirable a suitable heat treatment is generally necessary to neutralise these stresses and restore the metal to its original structure.*

The various cold working *operations* are :

1. Drawing
2. Sequeezing
3. Bending
4. Shearing
5. Hobbing
6. Shot peening
7. Cold extruding.

When there is excessive cold work the metal may fracture before reaching the desired shapes and sizes, and in order to avoid it cold working operations are carried out in *several steps.*

9.2.2. Hot Working

When plastic deformation of metal is carried out at temperature above the recrystallization temperature the processes performed on metals are termed as **hot working.**

- Hot working process can be considered as simultaneous *combination of cold working and annealing.* Any work hardening effect caused by plastic deformation is neutralised immediately by the effect of high temperature.
- Hot working process *facilitates metal shaping with low power requirements though it is expensive to handle hot materials.*
- In hot working there is *loss of metal by scaling and fine dimensional tolerance cannot be acieved.*
- Hot working *increases the density* since any pores or cavities in the cast metal disappear.

- *Grain structure becomes more refined.*

The various hot working *operations* are :

1. Rolling
2. Forging
3. Pipe welding
4. Hot working
5. Hot spinning
6. Hot extruding.

9.2.3. Comparison of Cold Working and Hot Working Processes

The comparison of cold working and hot working processes is given below .

S.No.	*Cold working*	*Hot working*
1.	Cold working is done at a temperature below the value required for recrystallization, so no appreciable recovery takes place during deformation.	Hot working is done at a temperature above recrystallization temperature, so it can be regarded as a simultaneous occurence of deformation and recovery process.
2.	Hardening is *not eliminated* as working is done at a temperature below recrystallization, so this is always accompanied by strain hardening.	Hardening due to plastic deformation is *completely eliminated* by recovery and recrystallization This is true, however, only if the rate of crystallization is higher than rate of deformation.
3.	Cold working *decreases* the value of elogation, reduction of area and impact values.	Mechanical properties like elongation, reduction of area and impact values are *improved*
4.	Crystallization does *not* take place, so refinement of crystals is out of question. Grains are elongated.	Refinement of crystals occurs.
5.	Uniformity of material is *lost* and properties are affected a lot.	Promotes uniformity of material by facilitating diffusion of alloys, constitutes and breaks brittle film of hard constituents or impurity, *e.g*, cementite in steel.
6.	Chances of crack propagation is more.	Cracks and unoxidised below holes are sometimes *welded up;* alternatively, serious cracks or faults are usually shown up at an early stage.
7.	Cold working *increases* ultimate tensile strength, yield point, hardness and fatigue strength while resistance to corrosion is *decreased.* If severely worked, yield point may coincide with ultimate strength value.	Ultimately tensile strength, yield point, fatigue strength, hardness and resistance to corrosion, etc. are *not affected* if hot working is done properly.
8.	Internal and residual stresses *are produced.*	Internal and residual stresses are *not produced.*
9.	Energy required for plastic deformation is *more.*	Energy required for plastic deformation is *less* because at high temperatures, metals become soft and ductile.
10.	*More stress* is required for deformation.	*Less stress* is required for deformation.

11.	No oxidation of metal occurs during working and hence pickling is *not required.*	Heavy oxidation occurs during working and pickling *is required* to remove the oxide.
12.	*Embrittlement does not occur* due to less diffusion and no reaction of oxygen at lower temperature.	Reactive metals get *severely embrittled* by oxygen and hence must be protected from the action of oxygen by using inert atmosphere.
13.	Surface decarburisation in steels does *not* occur.	Surface decarburisation in steels is *likely to occur* at higher temperatures unless the steel is protected by a proper atmosphere.
14.	Surface finish is *good.*	Surface finish is *not so good* due to oxidation at high temperatures.
15.	It is *easy to control* the dimensions within the tolerance limit.	It is *difficult to control* the dimensions because of contraction occuring during cooling.
16.	Ordinary steels can be used for shaping and hence the cost of the cold working plant is *less.*	Alloy steels are necessary for shaping and hence the cost of the hot working plant is *high.*
17.	Handling of materials is *easy.*	Handling of materials is *difficult.*

DESCRIPTION OF METAL FORMING PROCESSES

9.3. ROLLING

Rolling *is a forming operation on cylindrical rolls where in cross-sectional area of a bar or plate is reduced with a corresponding increase in length.* The metal is thinned and elongated by compression and shear forces but increased in width only slightly. Because of the high surface finish maintained on the rolls, the surface of the stock is burnished by the rolling action and attains a smooth bright finish.

A rolling may be two high, three high, four high, or six high depending upon the number of rolls stacked above each other as illustrated in Figs. from 9.1. to 9.4. The two high rolls being least expensive are most common for both hot and cold rolling.

Hot rolling consists of taking the hot ingot from a soaking pit, where it has been kept at an elevated temperature, and rolling it first into blooms (large oblong squares) and then through a series of other rollers into structural shapes, pipe, and tubing, Steel is nearly always rolled hot except for finishing passes on sheet. Copper is also rolled to rod, for making wire. Brass and nickel silver are usually cold rolled with many intermediate annealings. Fig. 9.5 illustrates grain structure during hot rolling. It is desirable that in all hot working the metal be heated throughout to the proper temperature before processing. If the temperature is non-uniform work hardening and crack may result.

Cold rolling is widely employed to produce a finish for hot-rolled metals. Sheets, strip, steel bar stocks such as shafting, flat wire etc. are produced by cold rolling. Most hot rolled material is cleaned (by acid cleaning solution) before it enters the cold rolling mill. Cold rolling is continued until the rolled section becomes too hard to continue the process, or until it reaches its final size.

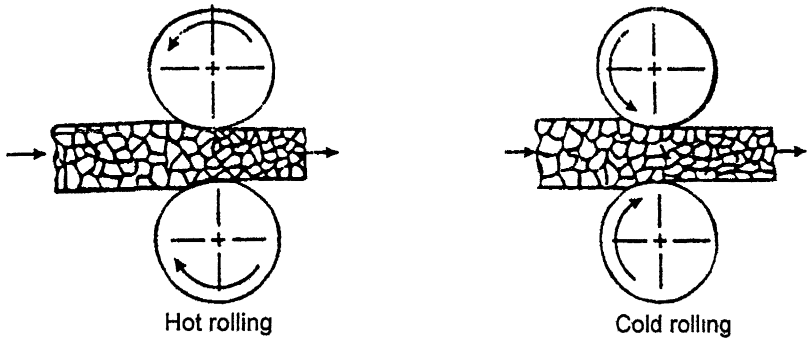


Fig. 9.1. Two high rolls.

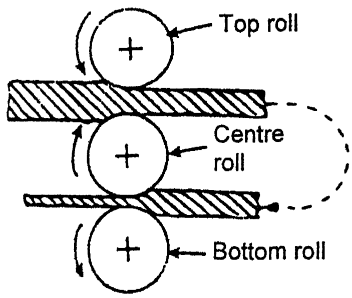


Fig. 9.2. Three high rolls.

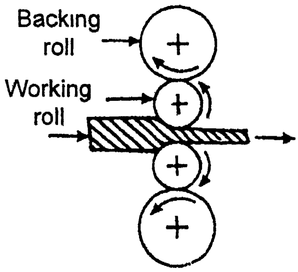


Fig. 9.3. Four high rolls.

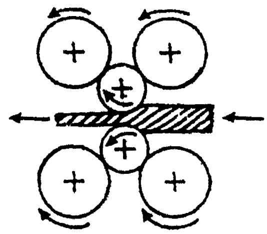


Fig. 9.4. Six high rolls.

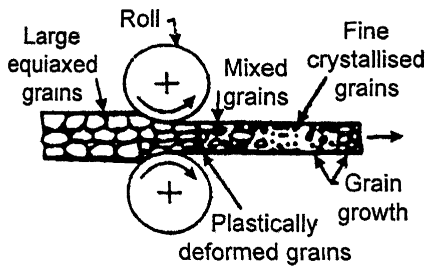


Fig. 9.5. Grain structure during hot rolling.

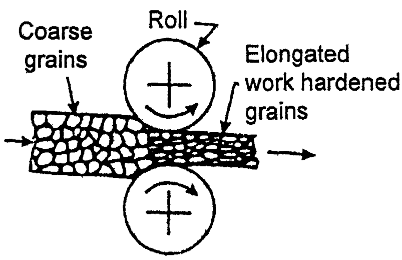


Fig. 9.6. Grain structure during cold rolling.

Fig. 9.6. shows the grain structure during cold working.

The cold rolling claims the following *advantages over hot rolling :*

(*i*) It gives improved physical properties by combining the cold work rolling with subsequent heat treatment.

(*ii*) It gives improved surface finish.

(*iii*) It produces thickness dimensions.

The two high reversing mill and three high mill are used to roll bars and plates that are up to 12 m length. For rolling strip, coils or sheets that may be thousands of metre in length, continuous mills are used.

The four high, six high and cluster roll (Fig. 9.7) arrangements are employed in hot rolling very wide plates and sheets, and in cold rolling, where the deflection of the centre of the roll would result in a variation of thickness. The small rolls (or working rolls) which are subject to wear, are less expensive and the large back up rolls provide required rigidity.

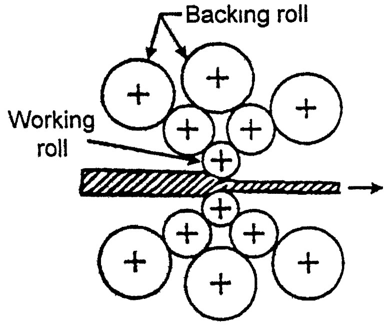


Fig. 9.7. Cluster roll.

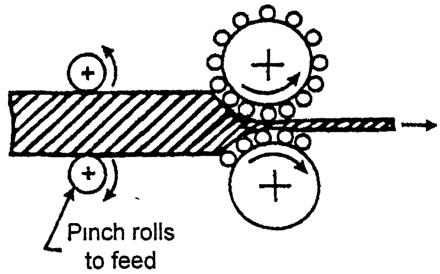


Fig. 9.8. Planetary mill.

Fig. 9.8 shows a planetary mill which employs rolls of very small diameter and effects very large reductions in a single pass on the material which is usually rolled hot.

Advantage of hot working over cold working processes :

The hot working processes entail the following *advantages* :

1. The crystal structure is refined.
2. The oriented structure is eliminated.
3. Porosity in the metal is largely eliminated.
4. The impurities in the form of inclusions are broken up and distributed throughout the metal.
5. Mechanical properties, especially elongation, reduction of area and Izod values are improved.
6. Greater homogeneity is developed in the metal.

9.4. FORGING

Forging *is the process by which heated metal is shaped by the application of sudden blows or steady pressure and characteristics of plasticity of material are made use of.*

Forging can be *classified* in two ways :

1. Hand forging.
2. Machine forging.

Hand forging :

Hand forging or blacksmithing is employed for small quantity production and for special work.

Generally speaking, the accuracy obtained is *less than that of drop forging.*

In hand forging the metal is heated in a Smith's forge or hearth (Fig. 9.9). It consists of a hearth for holding the fuel, a cast iron tuyere for supplying air blast to the fire, a centrifugal blower driven by a power preferably electric motor, to produce the blast, a chimney to carry the smoke and poisonous gases to air, a water tank behind the hearth to water cool the tuyere, a cool bunker to stock coal or coke, a water trough in front for quenching cutting tools and an air valve to control the blast. In operation, the work is paced in the fire pot and heated to the proper temperature for forging.

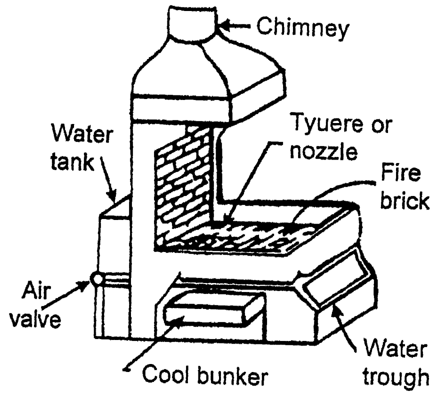


Fig. 9.9. Smith's forge.

Fig. 9.10 shows the various tools used in smithy. The list of important smithy tools and their uses are given below :

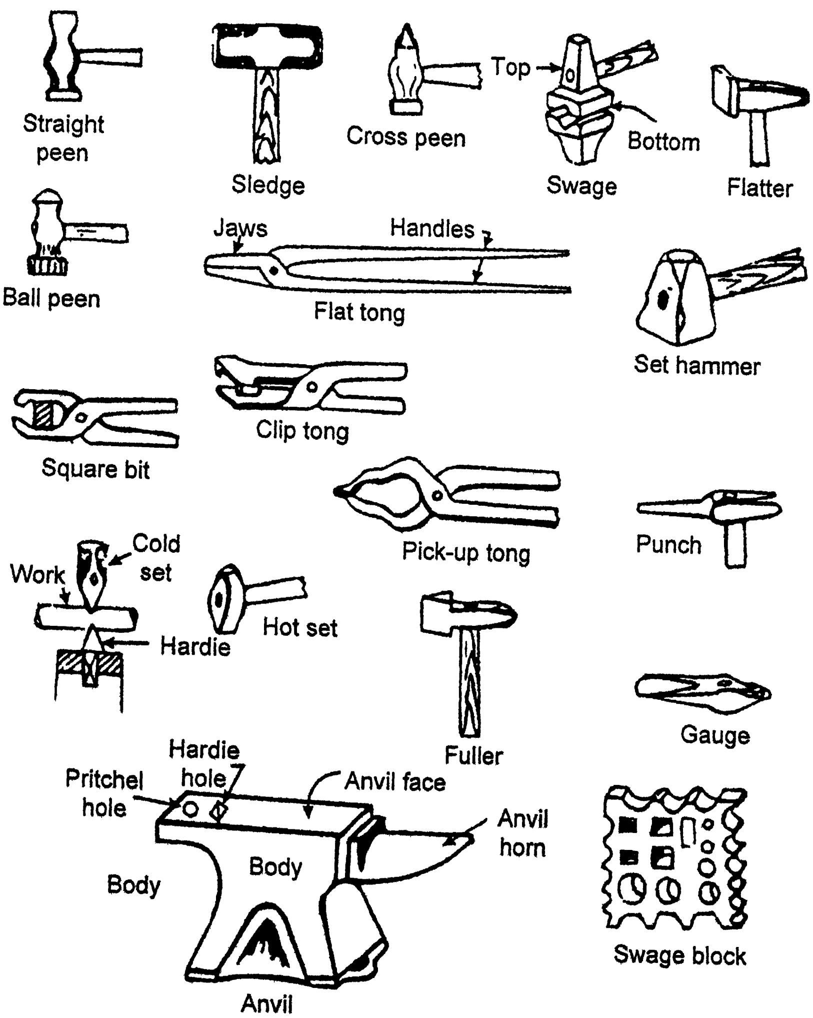


Fig. 9.10. Tools used in smithy.

Tools used in Smithy

Name of tool		*Use*
Sledge hammers, straight, flat and cross peen	—	To forge big jobs (heavy work).
Smith's ball peen hammer	—	To forge light and medium work.
Tongs, flat or square bit pick up long.	—	To hold the hot work.
Chisel long cold set	—	·To cut cold metal.
Hot set	—	To cut hot metal.
Fullers, top and bottom	—	To shape inside curves. To form corrugations for elongating metal.
Swages, top and bottom	—	To shape convex surfaces and to give finish to round, square, hexagonal or octagonal shaped sections.
Flatter or flattener	—	To give smooth finish to flat surfaces.
Set hammer	—	To form square shoulders and to clean the rounding in corners.
Punches	—	To make recesses of any shape in hot metal.
Hardie	—	To nick the bar and to shape the cold work.
Anvil	—	To forge, bend and shape the work.
Swage block	—	To shape or bend the work to any form and to knock heads of bolts etc.
Gauge	—	To cut plates to curves.

Forging on anvil is usually done with : (*i*) one man or (*ii*) two men-two handed working— the Smith and his Striker. The former uses a small hammer, the latter the sledge. To indicate, where he requires his mate to strike a blow the smith lightly taps the work wilh the small hammer; the striker's job is to hit the spot with the sledge. If working three handed the same procedure is followed, a light tap from the smith preceding a heavy one from the striker. To indicate when to finish, the smith taps the anvil with his hammer.

Upsetting (Fig. 9.11) *is the process of increasing cross-sectional dimensions when forging.* The process implies that the *cross-section is increased* and *the length decreased.* It may be done in a number of ways, each varying according to the details of the article required and the equipment in the shop. The simplest is to place the heated article on the anvil and hammer directly on the upper end. This increases the cross-section and reduces the length of the metal being worked.

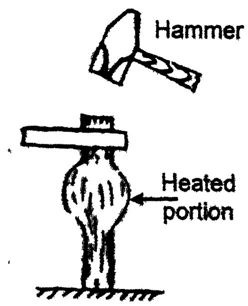


Fig. 9.11. Upsetting.

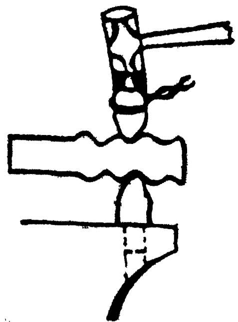


Fig. 9.12. Drawing down.

Drawing down is the process of increasing the length of a bar at the expense of its cross-sectional area. It is illustrated in Fig. 9.12. **Setting down** is *a localised drawing down or swaging operation. "Punching"* is the process of removing a slug of metal, generally cylindrical, by using a hot punch over the pritchel hole of the anvil, over a hole of correct size in the swage block.

Cutting out *is the process of cutting large holes of various shapes by using a hot chisel over a hole in the sewage block.*

Forging machines :

Forging machine *is one which is designed to shape a metal article while the material is in hot plastic state.*

The term forging machine in its widest sense includes :

(*i*) Drop stamp (whether of rope, belt or board type).

(*ii*) Steam hammer.

(*iii*) Pneumatic hammer.

(*iv*) Hydraulic hammer,

- The *drop stamp of board type* (Fig. 9.13) is a widely employed when shaping hot bars and finally to bring the work to size and shape between a set of drop stamping dies. In board hammer the tup is attached to a board which passes between two rollers. The latter run in an overhead attachment, are belt-driven and run in opposite directions. The tup is lifted by means of eccentric (foot, or hand operated or self acting) and they (eccentrics) cause the rollers to grip or release the board, when the board is gripped by the rollers their direction of rotation is such as to lift it (board) and the attached tup, when the board is released the tup falls with it. The height of lift depends upon the timing of release, which is instantaneous.

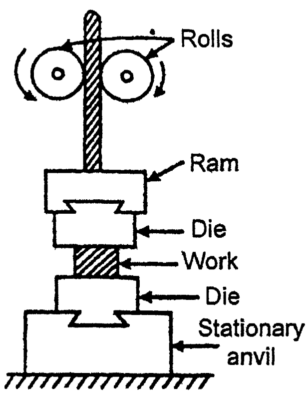


Fig. 9.13. Drop stamp of board type.

When producing small drop forgings or hot pressings the drop stamp in its various forms is a very effective method of obtaining the desired results. For shallow sheet metal work drop stamp is first class production machine as it permits a solid blow to be struck without any fear of bending a crank or breaking a press frame.

- A *steam hammer* operates on the principle of the steam engine. The main parts are frame, a steam chest or cylinder, piston, piston rod and the anvil. The hammer head is attached to the piston rod and is raised by admitting steam in the cylinder through the valve beneath the piston. The downward stroke of the hammer is obtained by exhausting the steam from beneath the piston and admitting from above the piston. The hammer descends by gravity and steam pressure is 5.5 to 8.5 bar. For varying the intensity of the hammer blows, light to heavy, steam is admitted below tne piston

while the hammer is descending to create cushioning to the falling hammer. The steam inlet and outlet are controlled by a special slide valve. For generating steam a boiler is required. A wide range of work is done on this class of forging machine.

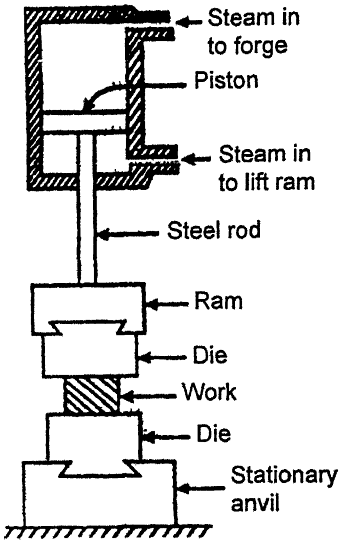


Fig. 9.14. Steam hammer.

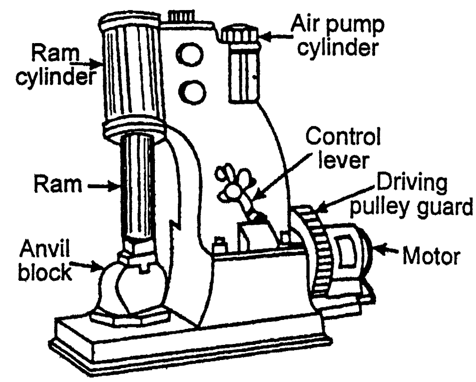


Fig. 9.15. Pneumatic hammer.

In *penumatic hammer* (Fig. 9.15) air is compressed on both upward and downward strokes of the piston which is worked by the electric motor. This compressed air is supplied to the ram cylinder by the long valve kept between the two cylinders which is moved by the control lever. By lowering and raising of control lever, the strokes and the speeds of the blows per minute can be varied from 50 to 200.

The steam and air hammers are designed to give sharp and fast blows, reproducing to a marked extent the action of the smith and his hammer. They may be used with a standard pair of anvils or with a set of dies, the latter often being so designed that the metal can be drawn out to the approximate length and width, and then placed in the dies for the final shaping stage. The flash which is formed is clipped off as the last operation.

- For the large castings and in cases where a heavy pressure is required the use of *hydraulic hammer* is restored to. The hydraulic forging machine being sluggish in action cannot usually compare with the steam or air hammer which operate more quickly, for small and medium sized forgings. The *main advantage of the hydraulic forging press is that it gives a definite squeeze and the time element permits the material to flow.*

9.5. EXTRUSION PROCESSES

Extrusion is *the process in which metal is caused to flow through a restricted orifice so creating an extremely elongated strip of uniform, but comparatively small cross-section.* It is similar to cold drawing except that the material is pushed not pulled, through the hole in the die, and the operation is often carried out at high temperature.

The important *extrusion processes* are discussed below :

1. Hooker extrusion :

It is a cold extrusion process and is commercially applied mainly for the production of small, thin walled copper and aluminium seamless tubes and small cartridge cases. Here a cup is first formed by a suitable working, operation; extrusion then consists of elongating and thinning the walls of cup using a shouldered punch and die as shown in Fig. 9.16.

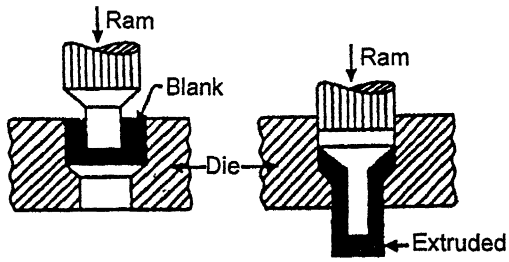


Fig. 9.16. Hooker extrusion.

2. Impact extrusion :

Refer to Fig. 9.17. It is quite similar to Hooker process, but the flow of metal is in *opposite direction.* This process is applied primarily to lead, aluminium, manganese, tin, zinc and their alloys. About 95% of die products of impact *extrusion are collapsible paste tubes.*

3. Direct extrusion :

Refer to Fig. 9.18. In direct extrusion a billet (piece of metal worked to a suitable shape) of the material to be extruded is placed in a container. At one end of the container is fixed a die while from the other end the metal is forced to flow through the die by hydraulically driven ram through the use of follower pad.

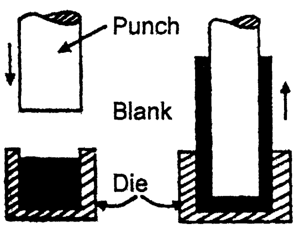


Fig. 9.17. Impact extrusion.

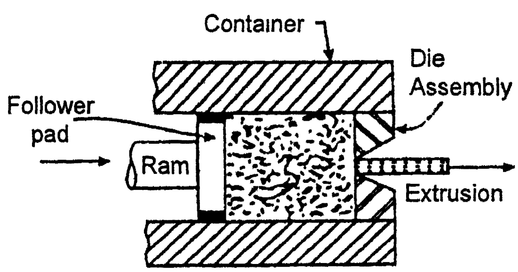


Fig. 9.18. Direct extrusion.

Much work must be supplied to overcome the resistance and high frictional forces between the billet and wall of the container and to produce the required rate of deformation.

4. Indirect extrusion :

The process shown in Fig. 9.19 is that of indirect or inverted extrusion, the main difference from direct extrusion being that there is little or no relative movement between the container walls and the billet, with less frictional force at this interface. Indirect extrusion requires less force than direct extrusion because the entire billet is not required to slide in the press

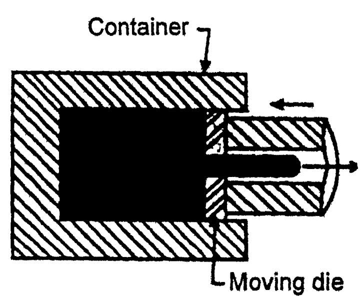


Fig. 9.19. Indirect extrusion.

container and therefore, much of the side-wall fliction is eliminated. *The use of indirect extrusion is restricted due lo the fact that the ram must be hollow and that the extrusion product must be passed back through the ram. The process of direct extrusion is generally mechanically more convenient.*

The presses for extrusion processes may be either hydraulic or mechanical, according to the pressure required, and either vertical or horizontal. The hydraulic press is more usually vertical since it has great flexibility, and compactness, and less liable to injury resulting from improper use. The mechanical vertical extrusion press gives a high output and each piece spends only a second or two in actual contact with the dies. This shortness of contact means that little heat is lost as a result of radiation and conduction, so that, if required little the extended part can be extruded and can be transferred straight to a reducing mill. *The dies employed are often of high speed steel and are always of high quality special alloy tool steels. The punches must also be of high quality steel. Lubrication is plentifully employed in most instances.*

- An important feature of the extrusion process in general is that *the grain of flow of the material lies in the direction most suited to resist imposed stresses in service.*

Metals that can be extruded include aluminium and its alloys, copper and its alloys, lead and its alloys, magnesium and magnesium alloys, steel; tin and zinc and their alloys, with few exceptions.

Advantages :

Extrusion process possesses the following *advantages* :

1. Shapes can be extruded, those if produced by other methods shall entail more cost comparatively.
2. Thinner walls can be obtained by increasing the forming pressure.
3. Due to high reduction ratio (the cross-sectional area of the billet to the cross-sectional area of the shape produced) the metal has excellent transverse flow lines, consequently the part has an added *strength and secondary operations are made easier.*
4. The extrusion dies are less expensive comparatively and so, moderately short runs are practical.
5. Extrusion process allows low cost in process redesign.
6. The *dimensional tolerances of extrusions are very good.*
7. There is more flexibility in design for adjacent thin and heavy sections as well as for difficult re-entrant angles. Sharp corners, not practicable in other processes can readily be obtained by extrusion.
8. Extruded shapes can often replace weldments and members previously machined from bar stock.
9. Extrusion is an ideal process for obtaining *rods from metal having poor ductility.*

Disadvantages and limitations :

The following are the *disadvantages and limitations* of extrusion process :

1. As compared to roll forming extruding speed is slow.

2. Though the accuracy is good and entirely adequate for most applications yet it is not as close as a machine part would be.
3. The size of dies and presses that can be economically built is a limiting factor.

9.6. WIRE DRAWING

- **Wire drawing** *is the process of reducing diameter of metal rods by drawing them through conical openings in die blocks.*
- Wire drawing is fundamentally a simple process. Steel, iron or non-ferrous rod is converted into wire by drawing it through a conical hole having an included angle of 8-24 degrees. *In continuous wire-drawing the wire passes through a succession of holes of decreasing size in dies made of steel, tungsten carbide, ruby or diamond, the reduction in cross-sectional area usually being about 30 per cent.*
- The rods used for wire-drawing are first pickled in acid to remove any scale and then electrically butt welded. The end of the rod is tapered sufficiently to fit the first dies by passing it through a pointing machine, which generally takes the form of two motor-driven rollers having a number of grooves of decreasing size between which the rod is rolled. The rod may be coated with iron hydroxide, copper or tin, applied during or after pickling. The rod is then fed into the wire drawing machine, which may be fitted with six or more dies, through which the wire is drawn by means of number of power-driven pulleys or rotating drums. Although the principle is similar in each case. the machines differ in design, and for practical purposes are broadly divided into *"non-slip"* and *"slip types"*.

Fig. 9.20 shows some important features of wire-drawing.

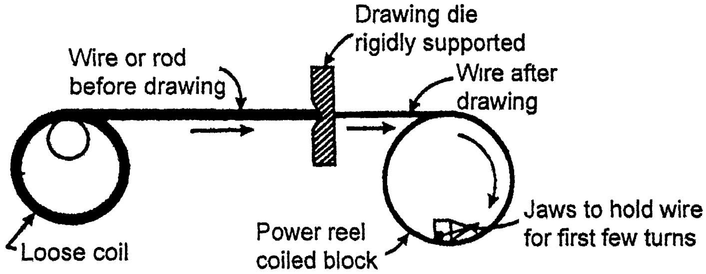


Fig. 9.20. Wire drawing.

- Due to the great heat generated by the friction of the wire in the dies, both the dies and drums are continuously cooled by circulating water through them. Lubrication is often ensured by passing tbe rod through dry soap on its way to the die. On some designs, however a synthetic lubricant is forced under pressure into dies, each of which is thus continuously lubricated over the whole of its surface. Separate cooling equipment is provided for the lubricant.
- A different method of overcoming the cooling, and lubrication problem is to employ a *wet-drawing machine operating on the slip principle.*
- Modem alloy-steel dies have a long life, but maximum efficiency *tungsten-carbide*

dies are replacing steel. Ruby or diamond dies are also employed but their use generally being confined to the drawing of fine wires of less than 3 mm in diameter. The jewels are first trimmed and then drilled with small drills which are fed with diamond powder and oscillated for several hours.

When the hole has been pierced it is finished and polished to within 0.00025 mm. The die is then mounted in a metal holder.

- When very fine wires are to be produced, a composite wire is employed for drawing. A platinum wire only 1/30,000 inch in diameter, for instance, many thousand times finer than a human hair, has been drawn by encasing the platinum wire in silver, thus increasing the overall diameter to a practicable figure. After drawing, the silver was dissolved by nitric acid, leaving a platinum wire which was visible only under a microscope.

9.7. COLD PRESSING AND DEEP DRAWING

- This process of mechanical shaping is mostly used for sheet metal of *special deep drawing quality.* The operations consist of making a suitable impression during the first stage followed by a number of redrawings. Different sets of dies are used for different operations. Hydraulic, pneumatic and mechanical presses are used depending upon the nature of the job.
- Some of the *common products of deep drawing are automobile bodies, lamp reflectors, cylinders and various small components required in the automobile industry.*
- The following materials are being used for deep drawing operations : Soft steel, copper, brass, aluminium and their alloys, magnesium and their alloys, zinc and a variety of other non-ferrous alloys.

Metals and alloys suitable for deep drawing should be of special deep drawing quality and should be tested, so that the required properties conform to the specifications specified. *Variation in grain size and the presence of harmful impurities will impart bad finish to the finished articles.* In the case of materials which workharden, stress relieving anneal may be necessary during one or more intermediate stages.

9.8. TUBE DRAWING

Tube drawing is accomplished in most cases with the use of a draw bench. Following are the different methods used for drawing tubes : Refer to Fig. 9.21.

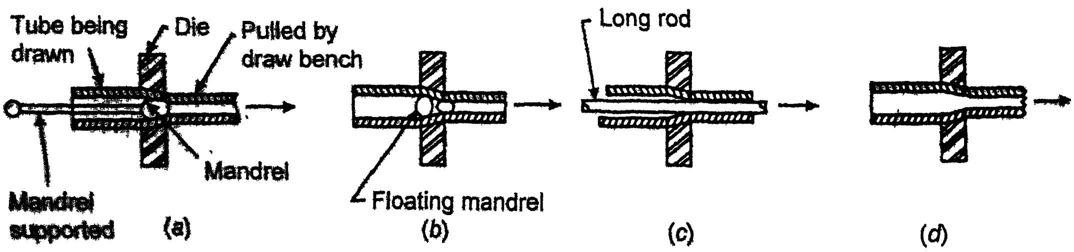


Fig. 9.21. Tube drawing

- Method (*a*) is most commonly used.
- Method (*b*) uses a floating mandrel which adjusts itself to the correct position because of its stepped contour.
- Method (*c*) is usually used for small-sized tubing.
- Method (*d*) uses no mandrel or rod and has little or no control over inside diameter

By repeated cold drawing and annealing, when necessary, it is possible to reduce a 50 mm diameter tube to a size of a hypodermic needle, which has an outside diameter of about 0.2 mm.

9.9. TUBE MAKING (By Rotary Piercing)

Here the material used is a *hot steel billet.*

The billet is gripped between two rolls which spin at high speed (Fig. 9.22). The spinning action tends to open a hole or cavity in the axis of the billet. A plug or mandrel bar is pierced through the centre and a round hole is easily produced. Rotary piercing is an important method, the rough pierced blank being finished by plug rolling over a mandrel between a pair of grooved rolls. For making tubes of large diameters the blanks are initially rough pierced and then given a second larger piercing before being finally rolled.

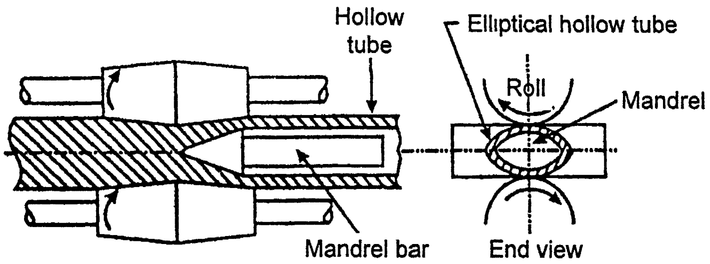


Fig. 9.22. Tube making.

9.10. BLANKING

- **Blanking** *is a process of cutting or shearing a blank from sheet or strip material.*
- In the production of many articles from sheet metal under a press or by spinning, the process of blanking is often the first operation in the production cycle. Simply expressed, blanking is the process of shearing from sheet or strip metal a blank of a given shape. The term normally implies two things :
  (*i*) that the process is carried out under some type of press,. and
  (*ii*) that the entire edge of the resultant blank has been subjected to a shearing operation.

  Reduced to simplest terms, *a set of blanking tools consists of a bed and punch.* The latter is attached to the ram of the machine and the former is clamped to the bed of the press. When the tools are set, the punch should first enter the bed without touching the sides in such a manner as to damage the cutting edge. The clearance between the cutting edges is regulated to suit the thickness of the metal to be cut with the tools in position, the punch should be adjusted to enter the bed for the minimum distance necessary to give complete shear. If it is permitted to enter too

far, the *punch is subjected to unnecessary wear.* With tools in position and properly set, the tail end of the downward stroke of the ram forces the punch to carry the material it covers into the bed. The surrounding metal cannot enter, hence is sheared off. *In order to obtain a blank free from burr, that is with a clean sheared edge, particular attention should be given to the clearance and condition of the cutting edges.*

- Figure 9.23 shows a typical layout for a small set ot blanking tools. The punch is of the built-up type having a low-carbon steel shank, which is fitted in the press ram. and a hardened- steel cutting edge held by screws on to the face. The aim of having a built-up punch of this type is two fold. It gives a strong edge that will withstand the abrasive action for a considerable period without losing its size, and it permits a great economy in the use of expensive alloy steel. In this particular design the cutting edge is held in position by means of a spigot and hollow-head screws. To assist the clamping and make up the *"shunt height"* of the press, the bed is mounted on a bolster plate. It is located by means of strong dowels and clamped in position with hollow-head screws. For simplicity neither the dowels nor the screws are shown in the figure. *In order to guide the material a guide plate fitted with a stop is attached to the face of the blank bed. The guide plate also acts as a stripper and takes the scrap webbing off the punch.* It aids in getting a good blank, and a reasonable output per hour, as time is not wasted in having to pull the scrap clear by hand.

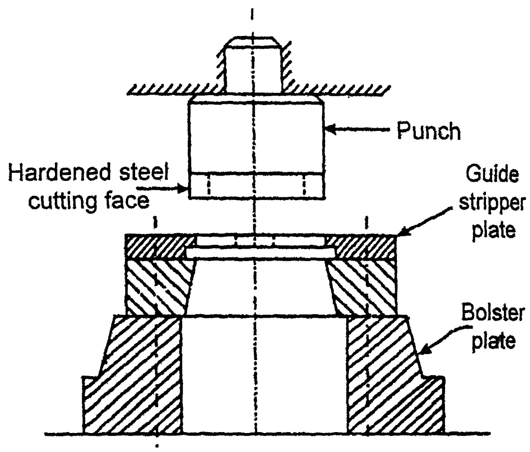


Fig. 9.23. Typical layout for a small set of blanking tools.

- For economic reasons the blanking operations is often combined with others which can be effected during the same work stroke of die press (*e.g.*, blanking and cupping).

9.11. PIERCING

The main difference between piercing and blanking is that the metal portions that are cut out in the former process are *scrap*. Holes of various shapes are pierced. When two or more piercing punches are employed together in a die, their lengths should differ slightly in order to reduce the force and impact required at one time. The diameters of holes which are to be pierced should be *at least twice the metal thickness, in order to avoid excessive punch breakage.* Pierced holes should not be located too close to adjacent holes. Drilling should be used for smaller holes and for holes which must be quite close together.

9.12. SPINNING (Metal)

Spinning *means shaping a metal blank as it revolves at a high speed in a lathe.*

It is one of the oldest methods of producing a wide range of goods which have an axis of rotation. For small-batch production, spinning, because of the simplicity of the equipment needed and the ease with which a chuck can be prepared, often gives *lower overall production costs than any alternative method.* The process lends itself to the production of goods *direct from a flat blank.* It is also a *very useful adjunct to the press and drop stamp.* In the latter direction it is used to finish articles that could not readily be handled by any other means. Hence the spinning lathe is often used along with the press or drop stamp to trim, bead, burnish or stroke over, neck down or spin a raising, cupping, or a shell to the desired size and shape.

In practice metal spinning may be roughly grouped under two headings :

1. Hand spinning.
2. Machine spinning.

I. Hand spinning :

Refer to Fig. 9.24. With hand spinning the blank, as it revolves at a high speed, is subjected by a steel tool. to pressure exerted by the operator, who has the tool handle tucked under his right arm. The tool is levered off a tree rest and is prevented from slipping by means of a peg. The leverage obtained is adjusted to suit the class of work being handled.

Skill in the use of the tools and experience in handling the varying classes of material is essential. If the metal is worked only in one place, it becomes work-hardened, and the result may be cracking, buckling or even tearing of the metal. The art in metal spinning lies in working the tool over the whole surface and coaxing the metal towards the desired cross-section. As the work proceeds and the surface becomes work-hardened, it is necessary to resort to inter-stage annealing.

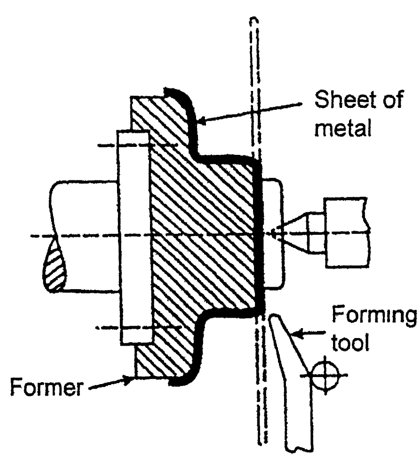


Fig. 9.24. Hand metal spinning.

2. Machine spinning :

Machine spinning is very similar to manual spinning, but is always used in conjunction with press to perform some operation that cannot be readily done on the latter type of machine. Rarely is machine spinning used to draught blank straight down. The method of operating is also different. In place of the tee rest and hand spinning tool, a compound slide is used in conjunction with a roller mounted in a fork. By constantly adjusting the positions of the slides the roller is made to give the desired contour. For machine spinning chucks are made from either cast iron or steel suitably hardened. The rollers are best made from a good alloy steel that will take a hard surface. For some jobs a rocking slide is also fitted to the machine and used

along with the compound rest. This permits such operations as trimming and beading to be done at the same setting as, say, spinning or burnishing.

9.13. EMBOSSING

- **Embossing** *is an operation of raising a design or form above the surface of a component by means of a pressing or squeezing action.* In practice, a wide range of machines is used for this purpose, such as the drop stamp, hand or friction screw press, the single-action crank or hydraulic press, the pneumatic or coining press.
- The operation may be such that a different inscription is given on either side of the metal blank. The best examples of this process occur in the manufacture of coins and metals. The *tool layout* is simple and consists of *a die having one impression, and a punch on which is cut the other.* When fitted in a suitable bolster the die is clamped to the bed of the machine; the punch is attached to the ram of the comparatively small, but exceedingly powerful press having a very short stroke and operating through a strong toggle or knuckle joint. The mechanism is capable of exercising a powerful squeeze, hence when an annealed and well-cleaned blank is inserted in the die the descending ram causes the metal to flow and fill the aperture between the tools. In this manner the reverse impressions of those cut on the punch and die are formed on the faces of the metal blank.
- Owing to the fact that this embossing operation is used extensively in the production of coins it is also known as ***"coining".***

COMPARISON OF METAL FORMING PROCESSES

The comparison of metal forming processes is given below :

S.No.	*Metal forming process*	*Advantages*	*Limitations*
1.	*Cold rolling*	(*i*) Suitable for production of plates, sheets and foils. (*ii*) High production rate. (*iii*) Good dimensional accuracy and finish.	(*i*) Deformation limited to small reductions. (*ii*) High equipment cost.
2.	*Hot rolling*	(*i*) Suitable for large reduction. (*ii*) High production rate. (*iii*) Wide range of shapes (Billets, blooms, slabs, sheets, bars, tubes and structural sections) can be produced.	(*i*) Suitable for production of large sections. (*ii*) High equipment cost. (*iii*) Poor dimensional accuracy and finish.
3.	*Drawing*	(*i*) Good surface finish and dimensional accuracy. (*ii*) Low equipment and tooling cost.	(*i*) Production of constant cross-sections only. (*ii*) Deformation limited to small reductions.

		(*iii*) High production rate. (*iv*) Long lengths of rounds, tubings, square and angles can be produced.	(*iii*) Lubrication is necessary.
4.	*Deep drawing*	(*i*) Moderate equipment and tooling cost. (*ii*) High production rate. (*ii*) Good surface finish.	(*i*) Forming of shallow or deep parts of simple shapes only. (*ii*) Limited to forming of thin sheets. (*iii*) Finishing required.
5.	*Hot extrusion*	(*i*) Suitable for large reduction. (*ii*) Moderate cost of equipment and toolings. (*iii*) Complex sections and long products can be produced.	(*i*) Components with thin walls arc difficult to produce. (*ii*) Only constant cross-section can be produced. (*iii*) Lubrication is necessary. (*iv*) Dimensional accuracy and finish achieved are not good.
6.	*Impact extrusion*	(*i*) Good finish and dimensional accuracy. (*ii*) High production rate. (*iii*) Generally no finishing is required. (*iv*) Suitable for production of thin sections.	(*i*) Deformation limited to small reductions. (*ii*) Suitable for production of light components from softer materials.
7.	*Punching and blanking*	(*i*) Low cost of labour. (*ii*) High production rate. (*iii*) Almost any shape can be obtained. (*iv*) Moderate equipment cost.	(*i*) Cost of tooling can be high. (*ii*) Limited to thin sheet applications.
8.	*Open-die forging*	(*i*) Simple to operate. (*ii*) Inexpensive tooling and equipment. (*iii*) Wide range of workpiece sizes can be used. (*iv*) Suitable for low production volume.	(*i*) Fairly skilled operators are required. (*ii*) Can be used for simple shapes only. (*iii*) Production rate is low. (*iv*) Dimensional accuracy and surface finish achieved are poorer. (*v*) Finishing required for achieving final shape.
9.	*Closed-die forging*	(*i*) Can be used for production of complex shapes. (*ii*) Suitable for high production rate. (*iii*) Good dimensional accuracy and reproducibility.	(*i*) Appropriate die set for production of each component. (*ii*) High equipment and tooling cost. (*iii*) More than one step required for each forging. (*iv*) Finishing required for achieving final shape.

QUESTIONS WITH ANSWERS

Q. 9.1. State the advantages and disadvantages of the following :
(*i*) Cold working; (*ii*) Hot working

Ans. 1. Cold working :

Advantages :

(*i*) Handling of material is easy.
(*ii*) Good surface finish and better dimensional accuracy.
(*iii*) Energy saving since heating is not required.
(*iv*) Strength, fatigue and wear properties are improved.
(*v*) Minimum contamination because of low working temperature.

Disadvantages :

(*i*) Ductility of metal is reduced.
(*ii*) Deformation energy required is high, so rugged and more powerful equipment is required, thus equipment cost is high.

2. Hot working :

Advantages :

(*i*) High production rate (since the process is faster).
(*ii*) Very high reduction is possible without fear of fracture.
(*iii*) Metal is made tougher because pores get closed and impurities are segregated.
(*iv*) Deformation energy required is low, hence less powerful equipments are required.
(*v*) Structure can be altered to improve the final properties.
(*vi*) The process does not change hardness or ductility of the metal since distorted grains soon change into new undeformed grains.

Disadvantages :

(*i*) Handling of material is not so easy.
(*ii*) Heat resistant tools are required which are expensive.
(*iii*) High temperature may promote undesirable reactions.
(*iv*) Close tolerances cannot be held because of non-uniform cooling and thermal contraction.
(*v*) Surface finish is poor because of scale formation.
(*vi*) Metalligical structure may be non-uniform because of cooling history after deformation.

Q. 9.2. What limits the maximum deformation in metal forming ?

Ans. In metal forming process the material plastically flows while the total volume of workpiece remains substantially constant but resulting in a corresponding change in the properties of the material. As a rule, the plasticity of metal increases with temperatures whereas its resistance to deformation decreases. The higher the temperature, the higher the plasticity and lower the yield point. Moreover no work hardening occurs at temperatures above recrystallisation temperature. This should be expected since recrystallisation denotes the formation and growth of new grains of metal from the fragments of the deformed grains, together with restoring any distortion in the crystal lattice.

In case of hot working the temperature at which deformation takes place is higher than recrystallisation. While in case of cold working it occurs at a temperature below the recrystallisation temperature of metal. So, we may say that *limit of metal forming is recrystallisation temperature of the metal.*

Q. 9.3. What is hydrostatic extrusion ?

Ans. *Hydrostatic expension* (Fig. 9.25) is an extrusion method in which the required pressure is applied through a fluid medium surrounding the billet. Although the presence of fluid inside the extrusion chamber *eliminates the container wall friction,* the process finds limited industrial application because of *need for specialised equipment and tooling and low production rate* (hight set-up time).

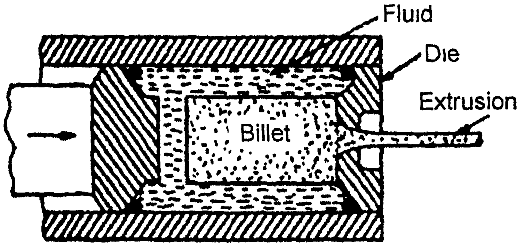


Fig. 9.25. Hydrostatic extrusion.

Q. 9.4. Explain briefly the process of forging.

Ans. Forging basically *involves plastic deformation of workpiece by compressing it between two dies to achieve the desired configuration.* Depending upon the complexity of the part to be produced, forging may be carried out with *open or closed dies.*

Simple components can be made by **"open-die forging"** by compressing the workpiece between two flat plates. Often open-die components are produced by repeated blows imparted by a mechanical hammer. The desired shape in this case is obtained by manually manipulating the workpiece between blows.

In **"closed-die forging"** the desired configuration is obtained by squeezing the workpiece between two shaped and closed dies. The upper half of the die is attached to the ram and the lower one to the anvil. On squeezing the die cavity gets completely filled and the excess metal comes out around the periphery of the die as flash which is later trimmed off from the forged component. Instead of press forging, drop forging is also used for closed-die forging. In the latter case, the workpiece kept in the lower die is forged by one or more blows by a guided falling hammer or ram. In press forging, a mechanical or a hydraulic process is used to slowly squeeze the workpiece. In this case forging is completed in a single closing of dies, hence the dimensional accuracy obtained is much better than that from drop forging.

Both open-die and closed-die forgings can be carried out in *hot or cold state.*

- **Cold forging** obviously requires *higher deformation energy* and is usually carried out *for only those materials which are sufficiently ductile at room-temperature.* Cold forged parts have *better dimensional accuracy and have good surface finish.*

'*Hot forged parts*' although require lower forces but give inferior finish and dimensional accuracy.

Q. 9.5. State the advantages and limitations of 'open-die forging' and 'closed-die forging'.

Ans. 1. Open-die forging :

Advantages :

(*i*) Simple to operate.

(*ii*) Suitable for low production volume.
(*iii*) Inexpensive tooling and equipment.
(*iv*) Wide range of workpiece sizes can be used.

Limitations :

(*i*) Low production rate.
(*ii*) Dimensional accuracy and surface finish achieved are poorer.
(*iii*) Finishing required for achieving final shape.
(*iv*) Fairly skilled workers are required.
(*v*) Can be used for simple shapes only.

2. Closed-die forging :

Advantages :

(*i*) Can be used for production of complex shapes.
(*ii*) Good dimensional accuracy and reproducibility.
(*iii*) Suitable for high production rate.

Limitations :

(*i*) More than one step required for each forging.
(*ii*) Finishing required for achieving final shape.
(*iii*) High equipment and tooling cost.
(*iv*) Appropriate die set for production of each component.

Q. 9.6. What do you mean by the following terms ?

(*i*) Coining; (*ii*) High-energy rate forming; (*iii*) Progressive piercing.

Ans. (*i*) **Coining.** The operation of coining is performed in dies that confine the metal and restrict its flow in a lateral direction.

(*ii*) **High-energy rate forming.** It includes a number of processes in which parts are formed at a rapid rate *by extremely high pressures.*

(*iii*) **Progressive piercing.** It is the method frequently employed on upset forging machines for producing parts such as *artillery shells* and *radial engine cylinder forgings.*

Q. 9.7. What is warm working ?

Ans. "*Warm working*" is deformation under the conditions of *transition, i.e.,* a working temperature between 0.3 and 0.6 times the melting point.

Q. 9.8. Explain briefly stretch forming process.

Ans. In order to form large sheets of thin metal involving symmetrical shapes or double-curve bends, a *metal stretch press* can be used effectively. In a simpler hydraulically operated press a single die mounted on a ram is placed between two slides that grip the metal sheet. The die moves in a vertical direction and the slides move horizontal. Large forces of 0.5 to 1.3 MN are provided for the dies and slides. The process is a stretching one and causes the sheet to be stressed above its elastic limit while confirming to the die shape. This is accompanied by a slight thinning of the sheet, and the action is such that there is little spring back to the metal once it is formed.

- The process *can be used with many hard-to-form alloys, there is little severe localised cold working, and the problem of unequal metal thin out is minimized.*

- *Scrap loss is fairly high* because material must be left at the ends and sides for trimming and there is a *limitation to the shapes that can be formed.*

Q. 9.9. What is electrohydraulic forming ?

Ans. Electrohydraulic forming, also known as *electrospark forming,* is a process whereby *electrical energy is directly converted into work.*

This process is *safe to operate and has low die and equipment cost. The energy rates can also be closely controlled.*

Q. 9.10. What is magnetic forming ?

Ans. Magnetic forming is another example of the direct conversion of electrical energy into useful work. At first it served primarily for swaging-type operations such as fastening fittings on the ends of tubes and crimping terminal ends of cables. More recent applications are embossing, blanking, focusing and drawing, all using the same power source but differently designed work coils.

The process has the *limitations :* Complex shapes may be impossible to form, pressure cannot be varied over the workpiece and present units are limited to 400 MPa pressure.

Q. 9.11. Explain various defects relating to forming processes.

Ans. 1. Defects in rolling :

(*i*) *Irregularies.* It leads to a trapping of scales which remain inside as laps.

(*ii*) *Non-metallic inclusions.* These defects are produced, expecially during the hot rolling of a thick slab, crocodile cracks, separate the product into two halves.

(*iii*) *Internal blow holes in the stock.* It results in an elongation of the blow holes and the product becomes weaker.

- All the above defects can be minimised by a *careful inspection of the billet and by keeping the roll smooth and clean.* To avoid the internal cracks, it is necessary to design the roll pass properly.

2. Defects in forging :

(*i*) *Scale pits.* These are shallow depressions caused by hot removing scale from the dies. The scale is subsequently worked into the surface of the forging.

(*ii*) *Mismatch.* A mismatch occurs in drop forging when the dies are incorrectly aligned, and results in a lateral displacement between portions of the forging.

(*iii*) *Unfilled section.* An unfilled section in similar to misrun in casting and occurs when metal does not completely fill the die cavity. It is usually caused by using insufficient metal or insufficient heating of metal.

(*iv*) Defects resulting from improper forging such as *seams, cracks, laps* etc.

(*v*) *Ingot defects* such as pipes, cracks, scabs and segregation.

(*vi*) Defects resulting from the melting practice, such as *dirt*, slag and blow holes.

(*vii*) Defects resulting from *improper heating* and *cooling of the forging* such as *burnt metal, decarburised steel* and *flakes.*

- These defects are found in all metals which are heated to plastic stage and then shaped.

3. Defect in drawing :

- The typical surface defects in rod and wire drawing are *due to a polughing by hard particles and local breakdown of the lubricating film.*
- The other kinds of defects include *formation of a buldge*, ahead of the die, with low reduction and high die angle, and the *development of a centre brust* with too large a deformation gradient along the cross-section.

4. Deep drawing defects :

- An *insufficient* blank holder pressure causes *to develop wrinkles on the flange, which may also extend to the wall of cup. Too much* of a blank holder pressure and friction may cause a *thinning of the walls* and a *fracture at the flange, bottom and corners* (if any).
- Due to the misplacement of the stock, *unsymmetrical flanges may result;* this defect is commonly known as ***miss strike.***
- The effect of a large grain size is to produce a *dull surface* (orange feel effect); this defect is also common in bending operations.
- While drawing a rolled stock, ear lobes tend to occur because of the anisotropy induced by rolling operation.

5. Extrusion defects :

- The most common defect in extrusion (known as extrusion defect) arises from the *back flow of the material*, pushing the end face of the billet into the core of the product. Such a defect *weakens the product* since the surface layer is normally contaminated by oxides.
- Sometimes the heat generated due to extrusion may raise the temperature of the job, resulting in the *development of surface cracks.*

Q. 9.11. What is work (or strain) hardening ?

Ans.
- Work (or strain) hardening is a *phenomenon* which results in an *increase in hardening and strength of a metal* (specimen) subjected to plastic deformation at temperature lower than the recrystallization range (cold working).
- When a material is subject to plastic deformation, a certain amount of work done on it is *stored internally as stain energy. This additional energy in a crystal results in strengthening or work hardening of solids.*

Thus *work (or strain) hardening may* be defined as *increased hardeness accompanying plastic deformation.* This increase in hardening is accompanied by an *increase in both tensile and yield strength.*

- Work hardening *reduces ductility and plasticity.*
- Work hardening is used in many manufacturing processes such as rolling of *bars and drawing of tubes.* It is also used to improve the elastic strength in the manufacture of many parts such as : (*i*) Prestretching of hoisting chains and cables, (*ii*) Initial pressurisation of pressure vessles, cylinders of hydraulic press and guns.

Mechanism of work hardening. *Work hardening is caused by dislocations interacting with each other and with barriers which impede their motion through the crystal lattice.* Hardening

due to dislocation interaction is a complicated problem because it involves large groups of dislocations, it is difficult to specify group behaviour in simple mathematical way. One of the easiest dislocation concepts to explain strain hardening was the idea that *dislocations pile up on slip planes at barriers in crystal. The pile ups produce back stress which opposes the applied stress on slip plane.* Another mechanism of work hardening in addition to that due to back stress resulting from dislocation pile up at barriers, is believed to occur when *dislocations moving in the slip plane cut through other dislocations intersecting the slip plane.* The dislocations threading through the active slip plane are often called a *dislocation forest* and this work hardening process is referred to the intersection of a forest of dislocations.

Theory of work hardening. According to all theories (of work hardening) work hardening is due to the increased resistance the dislocations experience in moving through the lattice when the metal has been subjected to cold working/deformation. The basic idea put forward by Taylor in 1934 was that work hardening is due to the *dislocations getting in each other's way.* Thus the stress (τ) necessary to move a dislocation in the stress field of other dislocations surrounging it, will have to have a higher value.

The value of τ is given by the relation :

$$\tau = K\left(\frac{b}{L}\right)^{1/2} \gamma^{1/2}$$

where, K = A constant,

b = Burger's vector,

L = A side of the dislocation loop if it is assumed that square loops are emitted ($L = R$ in case the dislocation loops are circular rings, where R is the radius of dislocation ring), and

γ = Plastic strain.

Q. 9.12. Explain the terms 'Recovery', 'Recrystallisation' and Grain growth. Give the differences between recovery and recrystallisation.

Ans. Recovery, Recrystallisation and Grain growth :

The deformed metal, in comparison with its underformed state, is in a non-equilibrium and thermodynamically unstable state. Subsequently, spontaneous processes occur in strain-hardened metal, even at room temperature. If the temperature is raised sufficiently, the metal attempts to approach equilibrium through the processes namely :

(*i*) Recovery,

(*ii*) Recrystallisation, and

(*iii*) Grain growth.

Fig. 9.26 shows a schematic diagram indicating recovery, recrystallisation and grain growth and changes in important properties in each region.

Recovery :

- *It is a low temperature phenomenon which results in the restoration of the physical properties without any observable change in microstructure.*

- During recovery, there is *negligible effect on hardness* whereas *electrical resistance decreases rapidly towards the annealed value.*
- The process of recovery is important for *releasing internal stresses in forging, moulded and fabricated equipments, cartridge cases and boiler tubes without decreasing the strength acquired during cold working.*

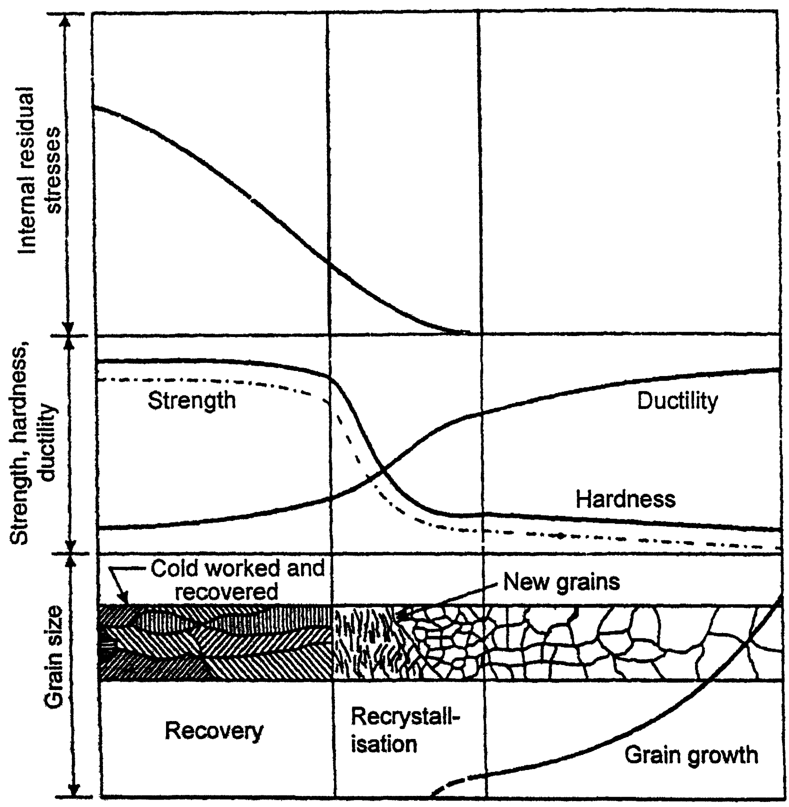


Fig. 9.26. Recovery, recrystallisation and grain growth.

Recrystallisation :

- ***It is a process by which distorted grains of cold worked metal are replaced by new strain free grains during heating above a specific minimum temperature called* recrystallisation temperature.**
- Recrystallisation temperature is a function of :
  (*i*) *Particular metal.*
  (*ii*) *Purity of metal :* Soluble impurities raise the recrystallisation temperature.
  (*iii*) *Metal/Alloys :* Recrystallisation usually occurs at a temperature of about 0.3 T_m in pure metals and about 0.5 T_m, in alloys, where T_m is the melting temperature.
  (*iv*) *Amount of prior deformation :* The greater the degree of cold work the lower the recrystallisation temperature and smaller the grain size.

(*v*) *Annealing time :* The longer annealing time decreases the temperature necessary for recrystallization.

(*vi*) *Grain size :* The finer the grain size of cold worked metal, the lower is the recrystallisation temperature.

- The process of recrystallisation can be divided into *three states :*
  (*i*) Nucleation
  (*ii*) Primary grain growth
  (*iii*) Secondary grain growth.
- During **nucleation** *small strain free nuclei form at points at crystal grain boundaries in the heated structure.*
- In the **primary grain growth** the nuclei grow into grains until they first meet, replacing the old grains by new ones, that are now strain free and ultimately **secondary grain growth** which is accompanied with new grain growth at the expense of others and are small in size. During prolonged heating at high temperature the grains grow rapidly and produce locally exaggerated grain growth.

Grain growth :

— *Grain growth is an increase in grain size.*

— When the material is held for longer times at temperature above crystallisation temperature, or when it is healed to a higher temperature the *grain size increases* and there is *decrease in hardness and strength and gain in ductility. The decrease in hardness is not as sharp as during recrystallisation.*

— At a given temperature the grain size D at a given time is given by the following relation known as the *law of grain size :*

$$D^2 - D_0^2 = C.t$$

where, D = Grain size at a given time,
D_0 = Initial grain size,
C = Constant of proportionality, and
t = Time.

— The process of grain growth depends largely on the following factors :
(*i*) Annealing temperature
(*ii*) Annealing time
(*iii*) Rate of heating
(*iv*) Degree of prior deformation
(*v*) Insoluble properties
(*vi*) Alloying elements.

Differences between Recovery and Recrysallisation

S.No.	Aspects	Recovery	Recrystallisation
1.	*Process*	A cold worked metal consists of networks of dense dislocations. Rearrangement of these dislocations to reduce lattice energy takes place due to polygonisation during recovery stage and is assisted by thermal activation. Polygonisation is a mechanism in which dislocations of the same sign align themselves into walls to form small angle subgrain boundaries.	As the temperature is increased, the dislocation networks in a cold worked metal tend to contract and regions of initially low dislocation density begin to grow. The driving force for recrystallisation comes from the stored energy of cold work. The elimination of subgrain boundaries is a basic part of recyrstallisation process.
2.	*Temperature*	It involves low *temperature* for the same metal.	It involves *higher temperature.*
3.	*Effect on properties of metal*	Internal stresses are released without decreasing the strength acquired by cold working. Electrical conductivity and ductility *increase r*apidly towards the annealed value during recovery.	Strain hardening is removed and with that is removed the increased strength at rapid rate. Internal stress is completely eliminated. There is slow further improvement in electrical conductivity and ductility during this stage. Grain size gets refined.
4.	*Change in micro-structure*	There is restoration of strain-free state without any change in microstructure of the cold worked metal.	There is replacement of cold worked structure by a new set of strain-free grains
5.	*Change in grain size*	No change	Slight increase.

HIGHLIGHTS

1. *Rolling* is a forming operation on cylindrical rolls where in cross-sectional area of a bar or plate is reduced with a corresponding increase in length.
2. *Forging* is the process by which heated metal is shaped by the application of sudden blows of steady pressure and characteristics of plasticity of material is made use of.
3. *Extrusion* is the process in which metal is caused to flow through a restricted orifice so creating an extremely elongated strip of uniform, but comparatively small cross-section.
4. *Wire drawing* is the process of reducing diameter of metal rods by drawing them through conical openings in die blocks.
5. *Blanking* is a process of cutting or shearing a blank from sheet or strip material.
6. *Spinning* means shaping a metal blank as it revolves at a high speed in a lathe.
7. *Embossing* is an operation of raising a design or form above the surface of a component by means of a pressing or squeezing action.
8. *Casting* means the pouring of molten metal into a mould, where solidification occurs.
9. *Machining* is the process of cold working the metal into different shapes by using different type of machine tools.

OBJECTIVE TYPE QUESTIONS

Fill in the Blanks/Choose the Correct Answer :

1. The most important property of metal is elastic/plastic deformation and it is extensively used for fabrication by mechanical working.
2. A metal is said to be cold/hot worked, if it is mechanically processed below the crystallisation temperature of the metal.
3. Residual stresses are set up during hot/cold working.
4. Shot peening is a cold/hot working operation.
5. When plastic deformation of metal is carried out at temperature above the recrystallisation temperature the processes performed on metal are termed as cold/hot working.
6. .... working process can be considered as simultaneous combination of cold working and annealıng.
7. Pipe welding is a cold/hot working operation.
8. Hardening is not eliminated in cold/hot working process.
9. Cold/hot working decreases the value of elongation.
10. Refinement of crystals occurs in hot/cold working processes.
11. In cold/hot working chances of crack propagation is more.
12. In hot/cold working internal and residual stresses are not produced.
13. Rolling/casting is a forming operation which is carried on cylindrical rolls.
14. The two/three/four/six high rolls being least expensive are most common for both hot and cold rolling.
15. .... rolling is widely employed to produce a finish for hot rolled metals.
16. Cold/hot rolling gives improved surface finish.
17. Cold/hot rolling produces thickness dimensions.
18. For rolling strips, coils or sheets that may be thousands of metre in length .... mills are used.
19. Steel is nearly always rolled hot/cold for finishing passes on sheet.
20. Brass, nickel and silver are usually cold/hot rolled with many intermediate annealings.
21. If the temperature is uniform/non-uniform work hardening and crack may result.
22. In cold/hot rolling crystal structure is refined.
23. Forging/casting is the process by which heated metal is shaped by the action of sudden blows or steady pressure.
24. Flattener/punch is used to give smooth finish to flat surfaces.
25. Gauge/hardie is used to cut plates to curves.
26. Drawing down/setting down is the process of increasing the length of the bar at the expense of its cross-sectional area.
27. A drop stamp/steam hammer works on the principle of the steam engine.
28. Hooker extension is cold/hot extrusion process.
29. About 95% of the products of impact extrusion are .... paste tubes.
30. Indirect extrusion requires less/more force than direct extrusion.
31. The dimensional tolerances of extrusions are very good/good.
32. Wide drawing/tube drawing is the process of reducing diameter of metal rods by drawing them through conical openings.

33. Blanking/piercing is a process of cutting or shearing a blank from sheet or strip material.
34. .... holes should not be located too close to adjacent holes.
35. Spinning/blanking means shaping a metal blank as it revolves at a high speed in a lathe.
36. Casting/forging means the processing of molten metal into a mould, where solidification occurs.
37. Die/centrifugal casting has excellent surface finish and dimensional accuracy.

ANSWERS

1. Plastic	2. Cold	3. Cold
4. Cold	5. Hot	6. Hot
7. Hot	8. Cold	9. Cold
10. Hot	11. Cold	12. Hot
13. Rolling	14. Two	15. Cold
16. Cold	17. Cold	18. continuous
19. Hot	20. Cold	21. Non-uniform
22. Hot	23. Forging	24. Flattener
25. Gauge	26. Drawing down	27. Steam hammer
28. Cold	29. collapsible	30. Less
31. Very good	32. Wire drawing	33. Blanking
34. Pierced	35. Spinning	36. Casting
37. Die		

THEORETICAL QUESTIONS

1. Define 'Rolling'. How does cold rolling differ from hot rolling ?
2. What do you understand by the term forging ?
3. Explain with the aid of neat sketches the various tools used in smithy.
4. Write short notes on :
   (*i*) Drop stamp
   (*ii*) Steam hammer
   (*iii*) Pneumatic hammer
   (*iv*) Hydraulic hammer.
5. (*i*) What is extrusion ?
   (*ii*) Enumerate and describe briefly the important extrusion processes.
6. State the advantages, disadvantages and limitations of extrusion process.
7. What are the metallurgical advantages of hot working over cold working processes?
8. (*i*) Explain briefly with a neat sketch the process of extrusion.
   (*ii*) What are the advantage of extrusion over rolling and forming ?
9. Explain briefly any three of the following metal forming processes :
   (*i*) Spinning (*ii*) Blanking
   (*iii*) Piercing (*iv*) Wire drawing
   (*v*) Embossing (*vi*) Tube making.

Group-B

- Fundamentals of Metal Cutting
- Fundamentals of Grinding and Finishing
- Unconventional Machining Processes
- Fundamentals of Welding and Allied Processes
- Need for Integration
- Group Technology
- Simulation and Data Base Management System
- Elements of Integration
- Product and Process Design for Integration
- Computer Aided Process Planning
- Inspection and Quality Control
- Micellany

10

Fundamentals of Metal Cutting

*10.1. Machining processes — Machining — Classification of machining processes, 10.2. Cutting tools — General characteristics of a metal cutting tool — classification of cutting tools — characteristics of a ideal cutting—tool material — types of tool materials — cutting fluids — machinability — tool life — orthogonal and oblique cutting — types of chips —forces of a single-point tool, 10.3. Machine tools, 10.4. Lathe — Introduction — parts of lathe — size and specifications of lathe — types of lathe — lathe tools — lathe operations — lathe accessories — eccentric turning — thread rolling — cutting speed, feed and depth of cut — testing of lathes, 10 5. Drilling machines — Introduction — specifications of a drilling machine — operations performed — classification of drilling machines — cutting speeds and feeds — work holding devices — drill holding devices — drilling machine tools, 10.6. Shaping machine (Shaper) — Introduction — classification of shapers — principal parts, 10.7 Planing machine (Planer) — Introduction — comparison between planer and shaper — types of planer — principal parts of a planer — size of a planer — standard clamping devices — planer operations, 10.8. Milling machine — General aspects — specifications of a milling machine — types of milling machines — main parts of a horizontal milling machine — types of milling machines — main parts of a horizontal milling machine — types of milling cutters — milling operations — cutting speed, feed and depth of cut, 10.9. Comparison of machining processes, 10.10. CNC Machines and CAD/CAM — Introduction to modern machine tools — NC machines — Introduction — working of NC machine tool — main elements of NC machine tool — classification of NC machines — applications of NC machines — advantages of NC machines — CNC machines — functions of CNC—advantages of CNC machines (over NC machines) — disadvantages of CNC machines — applications of CNC — Introduction to CAD/CAM — CAD — definition — advantages — CAM — general aspects — advantages — software and hardware for CAD/CAM —functioning of CAD/CAM system — Features and characteristics of CAD/CAM system — Application areas for CAD/CAM — **Questions with Answers** — Highlights — Objective Type Questions — Theoretical Questions.*

10.1. MACHINING PROCESSES

10.1.1. Machining

Machining *is the process of cold working the metals into different shapes by using different types of machine tools.* This process is mainly used to bring the metal objects produced by means of different fabrication techniques to final dimensions.

"Machinability" which is defined as the *ease of removing metal while maintaining dimensions and developing a satisfactory surface finish* is an important aspect affecting the metallurgical and properties stand-point of metals. Tool wear and power consumption are two

factors which affect the metal removal rate. Greater effort and time are required to keep the tools sharp due to rapid tool wear and frequent machine stoppage for replacing the dull tools. Types of *metal chips* formed during machining operation also affect the different characteristics. Machinability of a metal is generally indicated by *machinability ratings* (which are dependent upon their techniques of determination as well as upon the particular metal cutting operation used for their measurement).

Machining is accomplished with the use of machines known as *"machine tools"*. For production of variety of machined surfaces different types of machine tools have been developed. *The kind of surface produced depends upon the shape of cutting, the path of the tool as it passes through the material or both.* Depending on them metal cutting processes are called either turning or planing or boring or other operations performed by machine tools like lathe, shaper, planer, drill, miller, grinder, etc., as illustrated schematically in Fig. 10 1.

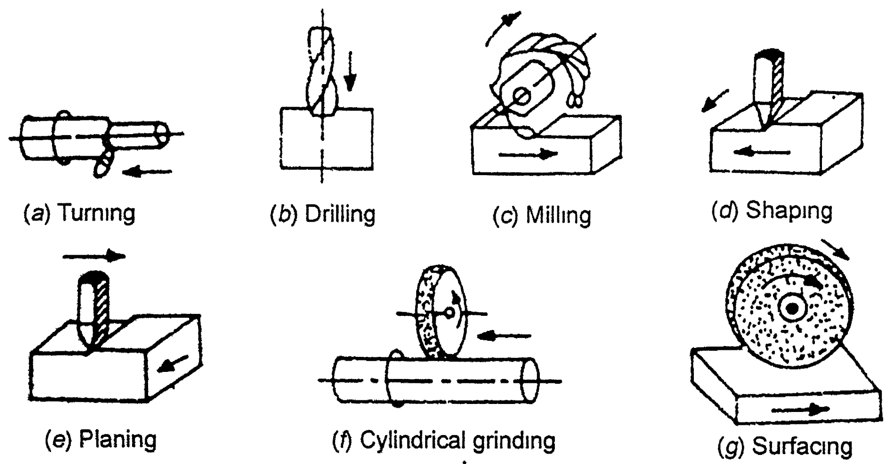


Fig. 10.1. Principal machining methods — Tool work interaction.

10.1.2. Classification of Machining Processes

Machining processes *are material removing operations in which the desired shape, size and surface finish on the finished product are obtained by removing surplus material.*

The machining processes are *classified* as follows :

1. ***Metal Cutting :***

(*i*) *Single point cutting :*

- Turning
- Boring
- Shaping
- Planing.

(*ii*) *Multi-point cutting :*

- Milling
- Drilling
- Tapping

- Hobbing
- Broaching.

2. ***Grinding and finishing :***

(*i*) *Grinding :*

- Surface grinding
- Cylindrical grinding
- Centreless grinding.

(*ii*) *Finishing :*

- Lapping
- Honing
- Superfinishing.

3. ***Unconventional Machining :***

- Ultrasonic machining
- Electrodischarge machine
- Electro-chemical machining
- Laser beam machining.

- The **metal cutting** (machining, a generic term, refers to all material removal processes) *refers to only those processes where material removal is affected by the relative motion between tool made of harder material and the workpiece.* The tool would be single-point cutting tool as used in operations like turning or shaping, or a multi-point tool as used in milling or drilling operation.
- **Grinding and finishing** processes are those where metal is *removed by a large number of hard abrasive particles or grains which may be bonded as in grinding wheels, or be in loose form as in lapping.*
- **Unconventional machining processes** are those *which use electrical, chemical and other means of material removal for shaping high strength materials and for producing complicated shapes.*

10.2. CUTTING TOOLS

10.2.1. General Characteristics of a Metal Cutting Tool

A typical cutting tool in simplified form is shown in Fig. 10.2; in this figure are shown the general characteristics of a metal cutting tool.

(*i*) **Rake angle.** *It is the angle between the face of the tool called the rake face and normal to the machining direction.* This angle specifies the ease with which a metal is cut. *Higher the rake angle, better is the cutting and less are the cutting forces.* There is a maximum limit to the rake angle and this is generally of the order of 15° for high speed steel tools cutting mild steel (increase in the rake angle reduces the strength of the tool tip as well as the heat dissipation).

It is possible to have rake angle as *zero* or *negative*. These are generally used in the case of highly brittle tool materials such as carbides or diamonds for giving extra strength to the tool tip.

(*ii*) **Clearance angle.** *This is the angle between the machined surface and underside of the*

tool called the flank face. The clearance angle is provided such that the tool will not rub the machined surface thus spoiling the surface and increasing the cutting forces. A very large clearance angle reduces the strength of the tool tip, and hence normally an angle of the order of 5-6° is used.

- The *conditions* which have an important influence on metal cutting are : (*i*) *Work material, (ii) cutting tool material, (iii) cutting tool geometry, (iv) cutting speed, (v) feed rate,* and *(vi) depth of cut and cutting fluid used.*
- The *cutting speed* (V) is the speed with which the tool moves through the work material. This is generally expressed in metres per second (m/s).
- *Feed rate (f)* may be defined as the small relative movement per cycle (per revolution or per stroke) of the cutting tool in a direction usually normal to the cutting speed direction.

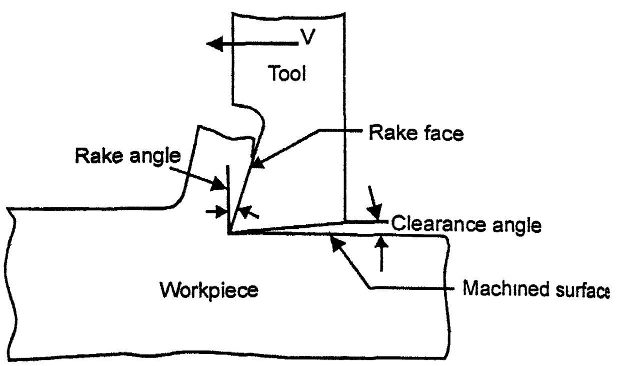


Fig. 10.2. General characteristics of a metal cutting tool.

- *Depth. of cut (d),* is the normal distance between the unmachined surface and the machined surface.

10.2.2. Classification of Cutting Tools

Cutting tools are *classified* as follows :

1. Single point cutting tools
2. Multi-point cutting tools
   (*i*) Solid tool
   (*ii*) Brazed tool
   (*iii*) Inserted bit tool.

The various angles of a single point tool are shown in Fig. 10.3.

10.2.3. Characteristics of an Ideal Cutting-Tool Material

An ideal cutting-tool must possess the following *characteristics :*

1. The material must *remain harder than work material at elevated temperature.* *(Hot hardness)*
2. The material must *withstand excessive wear* even through the relative hardness of the tool-work materials changes. *(Wear resistance)*
3. The material must have sufficient *strength and ductility* to withstand shocks and vibrations and to prevent breakage. *(Toughness)*
4. The *coefficient of friction* at the chip tool interface must remain low for minimum wear and reasonable surface finish.

5. The *cost and easeness of fabrication* should be within reasonable limits.

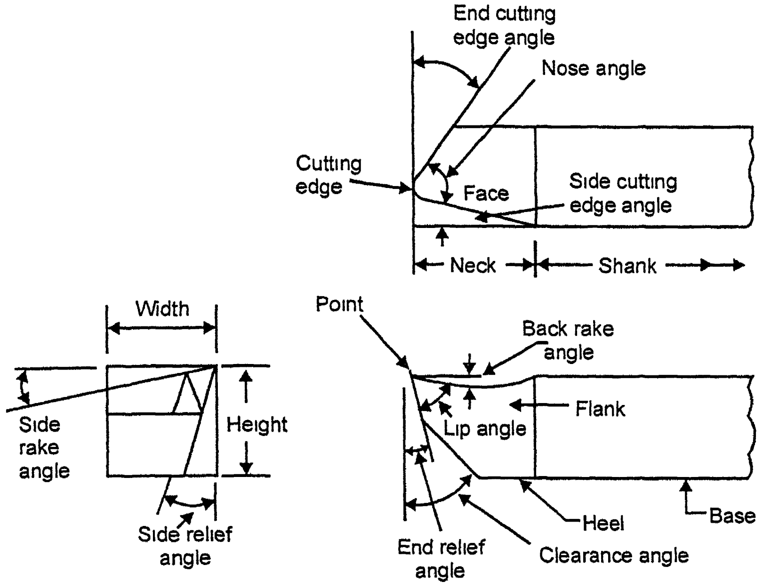


Fig. 10.3. Various angles of a single point tool.

10.2.4. Types of Tool Materials

- While selecting proper tool material the *type of service* to which the tool will be subjected should be given primary consideration. No one material is superior in all respects, but rather each has certain characteristics which limits its field of application.
- The *principal carbon tool materials* are :
  1. Carbon steels
  2. Medium alloy steels
  3. High speed steels
  4. Stellilies
  5. Cemented carbides
  6. Ceramics
  7. Diamonds
  8. Abrasives.

1. Carbon steels :

- *Carbon tool steels are characterised by the low stability of the supercooled austenite.* Therefore, they have a high critical cooling rate and a low hardenability. Through hardening can be achieved only in parts upto 12 to 15 mm in thickness or diameter. Consequently steel may be recommended for *small-sized tools*, which are quenched in oil or molten salts, and for comparatively large tools (15 to 30 mm diameter) in which the cutting section is only the surface layer (files, core drills, short reamers, etc.).

- When large tools are hardened (of diameter over 30 mm) the layer with a high hardness is so thin, even upon quenching in water, that the tools are not fit for cutting purposes.

Advantages :

(*i*) *Cheapness.*

(*ii*) *Low hardness* (BHN = 170 to 180).

(*iii*) Good machinability.

(*iv*) Formability in the annealed state.

(*v*) Retain a tough unhardened core due to low hardenability.

This last factor *improves their resistance to breakage under vibration and impacts*

Disadvantages :

(*i*) *Narrow range of hardening temperature.*

(*ii*) *Necessity for rapid quenching in water or aqueous alkali solutions (salt).*

This leads to *considerable deformation and warping and even to the formation of cracks.*

Therefore, tools of complex form with sharp changes in section and with a large length-to-diameter ratio should not be made of carbon steels. *Warping and crack forming may be reduced somewhat by quenching in water only to 200-250°C with subsequent retarded cooling in oil.* Stepped quenching (martempering) is advisable for small-size tools. Good results may be obtained in applying induction hardening to certain types of tools.

Uses : Carbon steels are only applicable for tools operating at low cutting speeds (about 12 m/min) since their hardness is substantially reduced at temperatures above 190-200°C.

2. Medium alloy steels :

- The high carbon medium alloy steels have a carbon content akin to plain carbon steels, but in addition there is, say, upto *5 per cent alloy content consisting of tungsten, molybdenum, chromium and vanadium.* Small additions of one or more of these elements *improve* the performance of the carbon steels in respect of *hot hardness, wear resistance, shock and impact resistance and resistance to distortion during heat treatment.*
- The alloy carbon steels broadly occupy a midway *performance position between plain carbon and high speed steels.*
- They lose their required hardness at temperature from 250 to 350°C.

3. High speed steels :

- *High speed steels are distinguished for their high red-hardness, their* capability to retain their structure (martensite), hardness, and wear resistance at the high temperature generated on the cutting edges when machining at high cutting speeds. High-speed steels are designed for the manufacture of high production tools *with high wear resistance which must retain their cutting properties at temperatures upto 600-620°C.*
- High speed steels are obtained by alloying tungsten, chromium, vanadium, cobalt and molybdenum with steel. This alloying produces metals which remain hard at temperatures at which normal steel becomes quite soft.

(*a*) **18-4-1 high speed steel :** A common analysis is : *18 percent tungsten, 4 percent chromium, and 1 percent vanadium,* with a carbon content of 0.6-0.7 percent. This alloy is termed 18-4-1, while an increase of vanadium to 2 percent provides 18-4-2 steel.

(*b*) **Cobalt high speed steels:** This is sometimes called *super high-speed steel* Cobalt is added from 2 to 15 percent to increase hot hardness and wear resistance. One analysis of this steel contains *20 percent tungsten, 4 percent chromium, 2 percent vanadium and 12 percent cobalt.*

(*c*) **Molybdenum high speed steels** : This class of high speed steels contains a *lower percentage of tungsten,* this being compensated by the addition of molybdenum.

This steel containing *6 percent molybdenum, 6 percent tungsten, 4 percent chromium and 2 percent vanadium have excellent toughness and cutting ability.*

4. Stellites :

- Stellite is a *non-ferrous alloy* with range of elements : *cobalt = 40 to 48 percent, chromium = 30 to 35 percent and tungsten = 12 to 19 percent.* In addition to one or more carbide forming elements, carbon is added in amounts of 1.8 to 2.5 per cent.
- They *cannot be forced to shape,* but may be deposited directly on the tool shank in an oxy-acetylene flame, alternately, small tips of cast stellites can be brazed into place.
- Stellites *preserve hardness upto 1000°C* and can be operated on steel at *cutting speed 2 times higher than for high speed steel.*
- These materials are not widely used for metal cutting, since they are very brittle, however, they are *used extensively in some non-metal-cutting application,* such as in rubbers, plastics where loads are gradually applied and the support is firm and where wear and abrasion are problems.

5. Cemented carbides :

- These are *so named because they are composed principally of carbon mixed with other elements.*
- The basic ingredient of most cemented carbide is *tungsten carbide which is* extremely hard. Pure tungsten powder is mixed under high heat at about 1500°C with pure carbon (lamp black) in the ratio of 94 percent and 6 percent by weight. The new compound, tungsten carbide, is then mixed with cobalt until the mass is entirely homogeneous. This homogeneous mass is pressed, at pressures from 100 to 420 MN/m^2, into suitable blocks and then heated in hydrogen. *The blocks are cut and ground into specified shapes and then sintered at high temperature heating in the presence of hydrogen.* Boron, titanium and tantalums are also used to form carbides.
- The amount of cobalt used regulates the toughness of the tool. A typical analysis of a carbide suitable for *steel machining is :*

Tungsten carbide = 82 percent

Titanium carbide = 10 percent
Cobalt = 8 percent.

- The *carbide tools* are made by *brazing or silve-soldering* the formed inserts on the ends of the commercial steel holders.
- The most important properties of cemented carbides *are very high heat and wear resistance.* Cemented carbides tipped tools *can machine metals even when their cutting elements are heated to a temperature of 1000°C. They can withstand cutting speed 6 or more than 6 times higher than tools of high-speed steels.*
- Cemented carbide is the hardest manufactured material and has extremely high compressive strength. However, it is very brittle, has low resistance to shock, and must be very rigidly supported to prevent cracking.

Types of cemented carbides :

The two types are :

1. Tungsten-type cemented carbides.
2. Titanium-tungsten type cemented carbides.

"Tungsten type cemented carbides" are *less brittle* than titanium-tungsten type; they contain 92 to 98 per cent tungsten carbide and 2 to 8 per cent cobalt. These cemented carbides are *designed chiefly for machining brittle metals such as cast iron, bronze, but they may also be used for non-ferrous metals and alloy steels etc.*

"Titanium-tungsten type cemented carbides" are more wear resistant. They contain 66 to 85 per cent tungsten carbide, 5 to 30 percent titanium carbide and 4 to 10 per cent cobalt. These cemented carbides are designed for *machining tougher materials chiefly for various steels.*

6. Ceramics :

- Ceramic tools are made by *compacting aluminium oxide powder in a mould at about 28 MN/m^2 or more.* The part is then sintered at 2200°C. This method is known as *cold pressing. Hot pressed ceramics are more expensive due to higher mould costs.*
- Ceramic tool materials are made in the form of the *tips* that are to be clamped on metal shanks.
- Ceramic toots have *very low heat conductivity and extremely high compressive strength, but they are quite brittle and have a low bending strength.* For this reason, these materials *cannot be used for tools operating in interrupted cuts, with vibrations, as well as for removing a heavy chip. But they can withstand temperatures upto 1200°C* and can be used at cutting speeds 4 times that of cemented carbides.
- Ceramic tools are *chiefly used for single-point tools* in semi-finish turning of cast iron, plastics and other work, but only when they are *not subject to impact loads.*
- To give increased strength to ceramic tools often ceramic with a metal bond, known as *"cermets"* is used.
- Because of the high compressive strength and brittleness the tips are given a 5 to 8 degrees *negative rake for carbon steel and zero rake fo? cast iron and non-metallic materials* to strengthen their cutting edge and are *well supported by the tool holder.*

- Ceramic tools are generally used *without a coolant since they have very low heat conductivity.*

7. Diamonds :

- The diamond (hardest-known material) can be run at *cutting speeds about 50 times greater than that for high speed tools, and at a temperature upto 1650°C.*
- In addition to its hardness the diamond is incompressible, *is of a large grain structure, readily conducts heat, and has a low coefficient of friction.*
- Diamonds are suitable for *cutting very hard materials* such as glass, plastics, ceramics and other abrasive materials and *for producing fine finishes.*
- The maximum depth of cut recommended is 0.125 mm with feeds of, say, 0.05 mm.

8. Abrasives :

- *Abrasive is a class of mineral used to sharpen the edges of cutting tools, and to reduce or polish metallic or other surfaces.*
- Abrasive particles held together by a bonding material comprise the cutting edges in grinding wheels known as *abrasive wheels.*
- There is fairly small group of generally used abrasives, some *natural,* some *artificial.* Of the *natural abrasives* perhaps the best known are *emery, corrundum and diamond dust.*
- *'Emery' is rough und durable,* containing about 70 percent aluminium oxide, a valuable abrasive which does the actual cutting and is known as crystalline fused alumina. While aluminium oxide occurs in nature, it is also produced synthetically by fusing the mineral bauxite in the electric arc furnace. *Corrundum contains about 90 percent aluminium oxide.*
- *Diamond dust is* slowly forging ahead as abrasive. When diamond dust is used in a "loose" condition it is mixed with oil or grease into a paste-like consistency.
- *"Carborundum"* is a trade name for *silicon carbide,* one of the *most important modern artificial abrasives.*

10.2.5. Cutting Fluids

Cutting fluids are used for the following *reasons :*

1. To cool the cutting tool and the workpiece.
2. To lubricate the chip, tool, and workpiece.
3. To help carry away the chips.
4. To lubricate some of the moving parts of the machine tool.
5. To improve the surface finish.
6. To prevent the formation of built-up-ridge.
7. To protect the work against rusting.

- However, the prime function of a cutting fluid in a metal cutting operation is to *control the total heat.* This can be done by dissipating the heat generated as well as reducing it. The mechanism by which a cutting fluid performs those functions are *cooling action* and *lubricating action.*

10.2.6. Machinability

Machinability *may be defined* as the *ease with which a material can be machined.* The more important criteria for *measuring* both tool performance and machinability are :

(*i*) The rate at which the material can be removed.

(*ii*) The smoothness and accuracy of the machined surface obtained.

(*iii*) The life of the cutting tool, or how long the cutting edge cuts satisfactorily before resharpening is required.

(*iv*) The power required for making the cut.

The relative machinability of a metal is expressed in percentage. All machinable metals are compared to a basic standard steel which is given an *arbitrary machinability rating* of 100%. The standard steel is a free cutting steel containing 0.13% carbon, 0 06 to 1.1% manganese and 0.08% to 0.03% of sulphur. The machinability index of a metal is given by the following relationship (this is a way to compare machinability of metals).

$$\text{Machinability index} = \frac{\text{Cutting speed of metal for 20 min. tool life}}{\text{Cutting speed of standard steel for 20 min. tool life}} \times 100.$$

10.2.7. Tool Life

Tool life *is defined as* the *time interval between the two successive regrinds.* It depends upon the following *factors :*

(*i*) Tool material.

(*ii*) Hardness of the material.

(*iii*) Type of material being cut.

(*iv*) Type of the surface on the metal (scaly or smooth).

(*v*) Profile of the cutting tool.

(*vi*) Type of the machining operation being performed.

(*vii*) Microstructure of the material.

(*viii*) Finish required on the workpiece.

Tool life of a cutting tool may be calculated by using the following relation :

$$VT^n = C$$

where, V = Cutting speed in m/min.,

T = Tool life in min.,

C = A constant (which is numerically equal to cutting speed that gives the tool life of one min.), and

n = Another constant (depending upon finish, workpiece material and tool material)
= 0.1 for H.S.S. steel tools ; 0.2 to 0.25 for carbide tools and 0.4 to 0.55 for ceramic tools.

The following are some of the ***possible tool failure criteria that could be used for limiting tool life :***

Based on tool wear :

(*i*) Wear land size.

(*ii*) Crater depth, width or other parameters.
(*iii*) A combination of the above two
(*vi*) Chipping or fine crachs developing at the cutting edge.
(*v*) Volume or weight of materials worn off the tool.
(*vi*) Total destruction of the tool.

Based on consequences of worn tool :

(*i*) Limiting value of change in component size.
(*ii*) Limiting value of surface finish.
(*iii*) Fixed increase in cutting force or power required to perform a cut

10.2.8. Orthogonal and Oblique Cutting

Orthogonal cutting : Refer to Fig. 10.4.

- When the tool is pushed into the workpiece, a layer of material is removed from the workpiece and it slides over the front face of the tool called rake face. *When the cutting edge of wedge is perpendicular to the cutting velocity, the process is called* ***orthogonal cutting.***

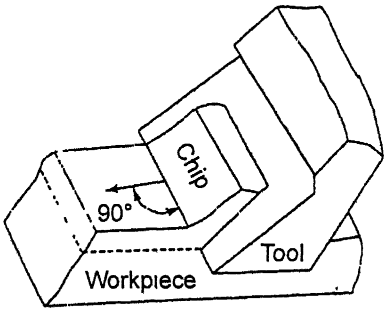


Fig. 10.4. Orthogonal cutting.

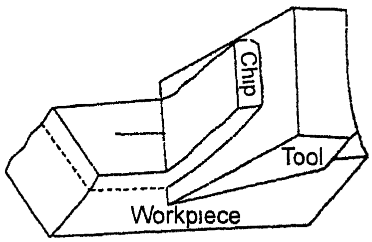


Fig. 10.5. Oblique cutting.

- In this case, the material gets deformed under plane strain conditions; the *chip slides directly up the tool face.*

Oblique Cutting : Refer to Fig. 10.5.

- In most practical metal-cutting processes, the cutting edge of the tool is not perpendicular to the cutting velocity but set at angle with the normal to the cutting velocity.
- *Cutting in this case takes place in three-dimensions (turning or milling) and represents the general case of oblique cutting.*
- In oblique cutting a *lateral direction of chip movement is obtained.*

Comparison between 'Orthogonal cutting' and 'Oblique cutting'

S.No.	*Aspects*	*Orthogonal cutting*	*Oblique cutting*
1.	*Inclination of the cutting edge of the tool.*	Perpendicular to the direction of tool travel.	Inclimed at an angle with the normal to the direction of tool travel.

2.	*Clearance of the workpiece width by the cutting edge*	The cutting edge clears the width of the workpiece on either ends.	The cutting edge may or may not clear the width of the work-piece.
3.	*The chip movement*	The chip flows over the tool face and direction of chip flow velocity is normal to the cutting edge. The chip coils in a tight flat spiral.	The chip flows on the tool face making an angle with the normal on the cutting edge. The chip flows side ways in a long curl.
4.	*Number of component of cutting force acting on the tool*	Only two components of the cutting force act on the tool. These two components are perpendicular to each other and can be represented in a plane.	Three components of the forces (mutually perpendicular) act at the cutting edge.
5	*Maximum chip thickness occurrence.*	Maximum chip thickness occurs at its middle.	The maximum chip thickness may not occur at middle.
6.	*Tool Life.*	Less	More.

10.2.9. Types of Chips

The chips produced, whatever the cutting conditions be, may belong to one of the following *three types* (See. Fig. 10.6).

1. Continuous chip; 2. Discontinuous chip; 3. Built-up chip.

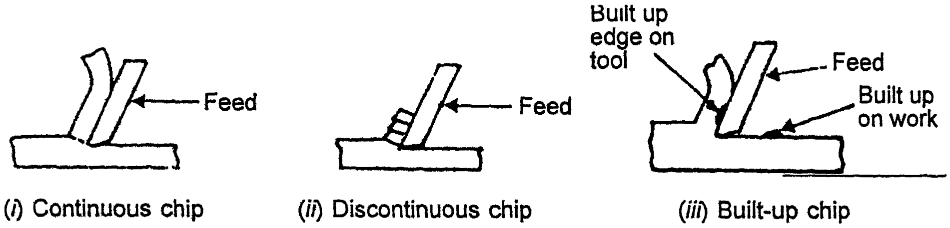


Fig. 10.6. Types of chips.

1. Continuous chip : Refer to Fig. 10.6 (*i*).

- These chips are produced while machining *more ductile materials.* This type of chip is *most desirable.*
- The continuous chip which is like a ribbon flows along the rake face. Production of continuous chips is possible because of ductility of metal.
- Some ideal conditions that promote continuous chips in metal cutting are :
  - — Small chip thickness (fine feed);
  - — Small cutting edge;
  - — Large rake angle;
  - — High cutting speed;
  - — Less friction between the chip tool interface through efficient lubrication.
  - — Ductile work materials.

- These chips are *most useful chips* since the *surface finish obtained is good and the cutting is smooth.* It also helps in *having higher tool life and lower power consumption.*

However, because of the large coils of chips, *chip disposal is a problem.* For this purpose various forms of *chip breakers* have been developed which are in the form of a step or groove in the tool rake face. The chip breakers allow the chips to be broken into small pieces so that they can be easily disposed off.

2. Discontinuous chip : Refer to Fig. 10.6 (*ii*).

- These chips are usually produced while cutting *more brittle materials* like grey cast-iron, bronze and hard brass.
- In this type the chip produced is in the form of *discontinuous segments* (deformed material instead of flowing continuously) gets ruptured periodically.
- Discontinuous chips are easier from the view point of chip disposal. However, the cutting force becomes unstable with the variation coinciding with the fracturing cycle. Also they generally provide better surface finish. However, in case of ductile materials they cause poor surface finish and low tool life.
- Discontinuous chips are likely to be produced under the following conditions :
  — Low cutting speeds;
  — Small rake angles;
  — Higher depths of cut (large chip thickness).

3. Built-up chip : Refer Fig. 10.6 (*iii*).

When machining ductile materials, conditions of high local temperature and extreme pressure in the cutting zone and also high friction in the tool-chip interface may cause the work material to *adhere or weld to the cutting edge of the tool forming the built-up edge (BUE).* This *causes the finished surface to be rough.* However, since the cutting is being carried by the BUE and not the actual tool tip, the *life of the cutting tool increases* while cutting with BUE. That way BUE is not harmful while rough machining.

10.2.10. Forces of A Single-point Tool

Refer to Fig. 10.7 :

Orthogonal cutting : Resultant, $R = \sqrt{F_x^2 + F_z^2}$

Oblique cutting : Resultant, $R = \sqrt{F_x^2 + F_y^2 + F_z^2}$

Torque to be developed on the workpiece,

$$T = \frac{F_z \times D}{2 \times 1000} \text{ Nm (neglecting the components } F_x \text{ and } F_y\text{)}$$

(where, D = diameter of the workpiece in mm)

Heat produced (= work done in cutting metal) $= \dfrac{F_z \times v}{60 \times 1000}$ kN m/s or kJ/s or kW

where, v = cutting speed in m/min.

$$\text{Power required} = \frac{F_z \times v}{60 \times 1000 \times \eta} \text{ kW}$$

(where, η = efficiency of the machine)

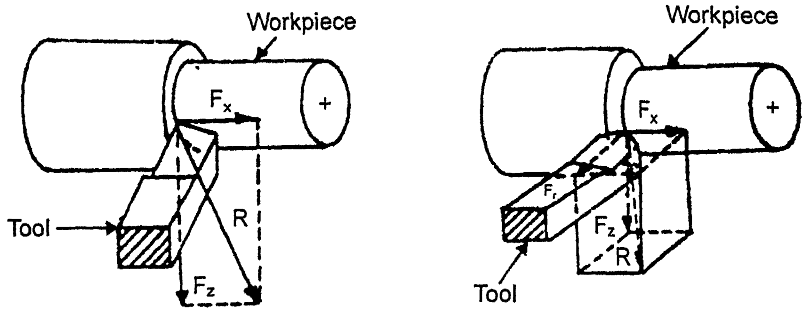


Fig. 10.7. Forces on a cutting tool.

The approximate values of efficiencies of the different machines when working at full loads are :

1. Lathes .... 80 to 90%
2. Drilling machines .... 85 to 90%
3. Milling machines .. .. 80 to 90%
4. Shapers and planers .... 65 to 75%
5. Grinding machines .... 80 to 85%.

10.3. MACHINE TOOLS

Machine tools are used for machining. They employ cutting tools to remove excess material from the given job. The machine tools can be *classified* as follows :

1. General purpose :

(*i*) Lathe (*ii*) Drilling machine
(*iii*) Shaping machine (*iv*) Planing machine
(*v*) Milling machine (*vi*) Sawing machine

2. Special purpose :

(*i*) Special lathes like capstan, turret and copying lathes
(*ii*) Boring machine (*iii*) Broaching machine
(*iv*) Production milling machine (*v*) Production drilling machine.

3. Automatic machine tools :

These machine tools, also called Automatic screw cutting machines (or simply auto-mats), are used for mass production of essentially small parts using a set of pre-designed and job-specific cams.

4. Computer Numerical Control (CNC) machine tools :

Under CNC machine tools, we have *CNC turning centre,* which does all the work of a lathe and *CNC machining centre* which does milling, drilling etc., with provision for automatic tool changing and tool wear correction built into it.

10.4. LATHE

10.4.1. Introduction. Refer to Fig. 10 8.

- A lathe is one of the oldest and perhaps most important machine tools ever developed. The job to be machined is rotated (turned) and the cutting tool is moved relative to the job. That is why, the lathes are also called *"Turning machines"*. If the tool moves parallel to the axis of rotation of the workpiece, cylindrical surface is produced, while it moves perpendicular to their axis, it produces a flat surface.

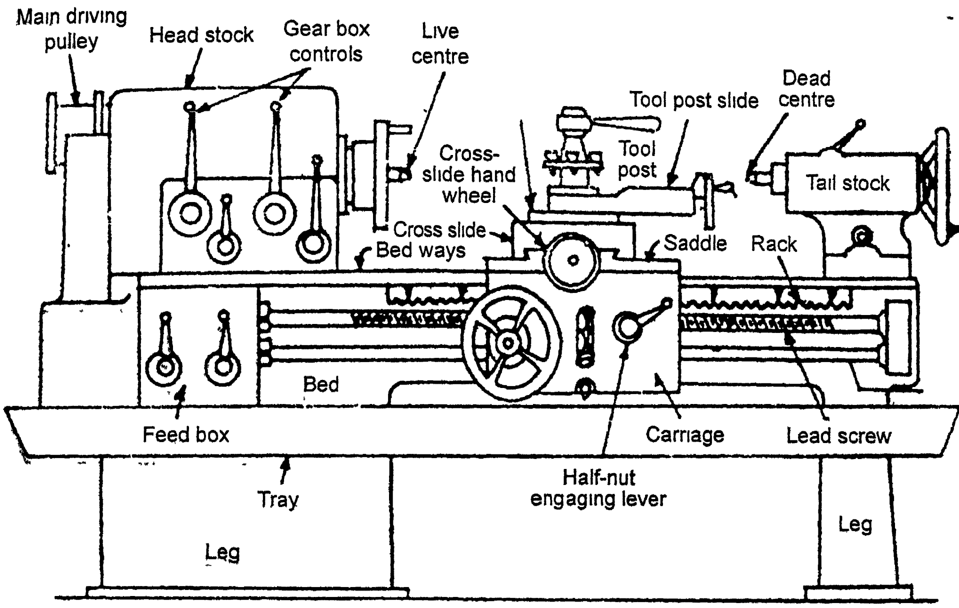


Fig. 10.8. Centre lathe.

- Fig. 10.9 shows the ***working principle of a lathe.*** In a lathe, the workpiece is held in a chuck or between centres and rotated about its axis at a uniform speed. The cutting tool held in tool post is fed into the workpiece for desired depth and in desired direction (*i.e.,* in linear, transverse or lateral direction). Since there exists a relative motion between the workpiece and the cutting tool, therefore the material is removed in the form of chips and the desired shape is obtained.

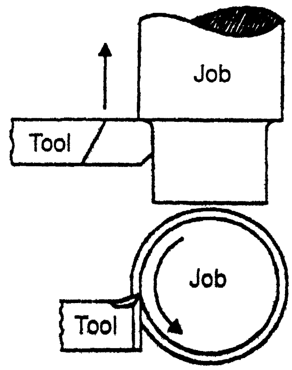


Fig. 10.9. Working principle of a lathe.

10.4.2. Parts of Lathe

1. Bed :

- It is a heavy, rigid casting made in one piece.
- It is the base or foundation of the lathe.

2. Headstock :

- It is permanently fastened to the innerways at the left hand end of the bed.

- It serves to support the spindle and driving arrangements.
- All lathes receive their power through the headstock, which may be equipped with a step-cone pulleys or a gear head drive (the modern lathes are provided with all geared type head stock to get large variations of spindle speeds).
- In order to allow the long bar or work holding devices to pass through, the head stock spindle is made hollow. A tapered sleeve fits into the tapered spindle hole.

3. Tailstock :

- It is situated at the right hand end of the bed.
- It is used for supporting the right end of the work.
- It is also used for holding and feeding the tools such as drills, reamers, taps etc.

4. Carriage :

- The carriage controls and supports the cutting tool.
- The carriage has the following five major parts :
  - (*i*) *Saddle.* It is a H-shaped casting fitted over the bed. It moves along the guide ways.
  - (*ii*) *Cross-slide.* It carries the compound slide and tool post ; can be moved by power or by hand.
  - (*iii*) *Compound rest.* It is marked in degrees ; used during taper turning to set the tool for angular cuts.
  - (*iv*) *Tool post.* The tool is clamped on the tool post.
  - (*v*) *Apron.* It is attached to the saddle and hangs in front of the bed. It has gears, levers and clutches for moving the carriage with the lead screw for thread cutting.

5. Feed mechanism :

- It is employed for imparting various feeds (longitudinal, cross and angular) to the cutting tool.
- It consists of feed reverse lever, tumbler reversing mechanism, change gears, feed gear box, quick change gear box, lead screw, feed rod, apron mechanism and half nut mechanism.

10.4.3. Size and Specifications of Lathe

Size of a lathe is *specified* in any *one* of the following ways :

1. The height of the centres measured over the lathe bed.
2. Swing or maximum diameter that can be rotated over the bed ways.
3. Swing or diameter over carriage. This is the largest diameter of work that will revolve over the lathe saddle.
4. Maximum job length in mm that may be held between the centres (headstock and tail-stock centres).
5. Bed length in metres which may include the headstock length also.
6. Diameter of the hole through lathe spindle for turning bar material.

10.4.4. Types of Lathe

The following are the types of lathe :

1. Speed lathe :

- In this lathe spindle can rotate at a very high speed with the help of a variable speed motor built inside the headstock of the lathe.
- It is used mainly for wood working, centering, metal spinning, polishing etc.

2. Engine or centre lathe :

- It is the most common types of lathe and is widely used in workshop.
- The speed of the spindle can be widely varied as desired which is not possible in a speed lathe.
- The cutting tool may be fed both in cross and longitudinal directions with reference to the lathe axis with the help of a carriage.

3. Bench lathe :

- It is usually mounted on a bench.
- It is very similar to speed or centre lathe, the only difference being it is smaller in size which enables it handle small work (usually requiring considerable accuracy such as in the production of gauges, punches and beds for press tools).

4. Tool room lathe :

- It is similar to an engine lathe, designed for obtaining accuracy.
- It is used for manufacturing precision components, dies, tools, jigs etc. and hence it is called as tool room lathe.

5. Turret and capstan lathes :

- These lathes have provision to hold a number of tools and can be used for performing wider range of operations.
- These are particularly suitable for *mass production of identical parts in minimum time.*

6. Automatic lathes :

- These lathes are so designed that the tools are automatically fed to the work and withdrawn after all operations, to finish the work, are complete.
- They require little attention of the operator, since the entire operation is automatic.
- These are used for mass production of identical parts.

7. Special purpose lathes :

These lathes are primarily designed for carrying out a particular operation with utmost efficiency.

10.4.5. Lathe Tools

- In a lathe, for a general purpose work, the tool used is a single-point tool (a tool having one cutting edge), but for special *operations multi-point tools may be used.*
- The commonly used materials are *high carbon steel, high speed steel, cemented carbides, diamond tips and ceramics.*

Depending upon the nature of operation done by the tool, the *lathe tools* are ***classified*** as follows :

(*i*) Turning tool (left hand or right hand)
(*ii*) Facing tool (left hand or right hand)
(*iii*) Chamfering tool (left hand or right hand)
(*iv*) Form or profile tool
(*v*) Parting or necking tool
(*vi*) External threading tool
(*vii*) Internal threading tool
(*viii*) Boring tool
(*ix*) Knurling tool.

The above mentioned tools are shown in Fig. 10.10.

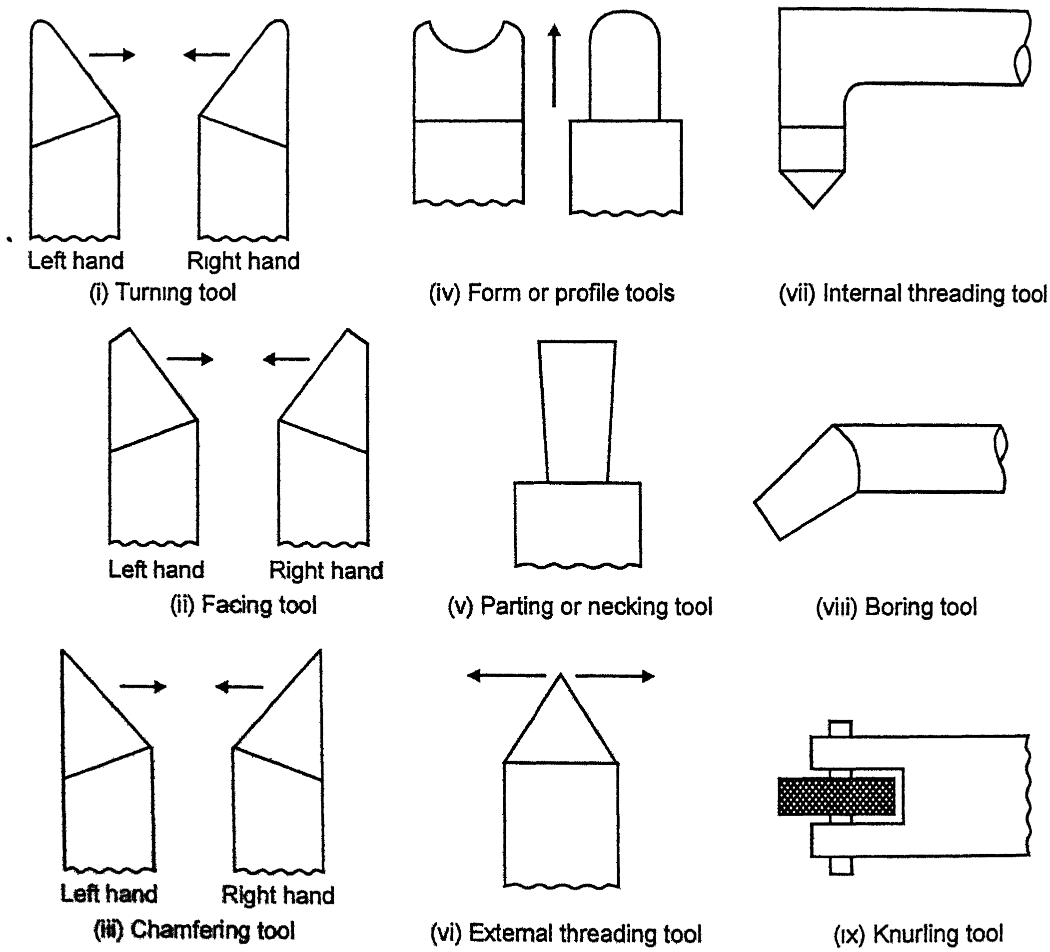


Fig. 10.10. Lathe tools.

10.4.6. Lathe Operations

Common lathe operations which can be carried out on a lathe are enumerated and briefly discussed as follows :

1. Facing	2. Plain turning	3. Step turning
4. Taper turning	5. Drilling	6. Reaming
7. Boring	8. Under cutting or grooving	9. Threading
10. Knurling	11. Forming.	

1. Facing. Refer to Fig. 10.11.

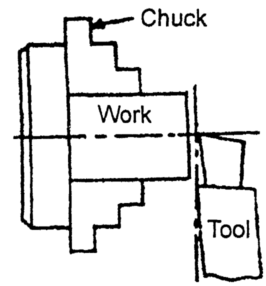


Fig. 10.11. Facing.

- *"Facing"* is an *operation of machining the ends of a workpiece to produce a flat surface square with the axis.* It is also used to cut the work to the required length.
- The operation involves feeding the tool *perpendicular* to the axis of rotation of the workpiece.
- A properly ground facing tool is mounted in the tool post. A regular turning tool may also be used for facing a large workpiece. The cutting edge should be set at the same height as the centre of the workpiece.
- The facing operation is usually performed in *two steps.*

In the first step a *rough facing* operation is done by using a heavy cross feed of the order of 0.5 to 0.7 mm and a deeper cut upto 5 mm (maximum). It is followed by a *finer cross feed* of 0.1 to 0.3 mm and a smaller depth of cut of about 0.5 mm.

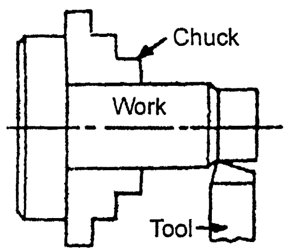


Fig. 10.12. Plain turning.

2. Plain turning. Refer to Fig. 10.12.

- It is an operation of removing excess material from the surface of the cylindrical workpiece.
- In this operation, the work is held either in the chuck or between centres and the longitudinal feed is given to the tool either by hand or power.

3. Step turning. Refer to Fig. 10.13.

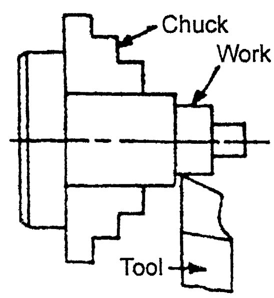


Fig. 10.13. Step turning.

- In this type of lathe operation various steps of different diameters in the workpiece are produced.
- It is carried out in the similar way as plain turning.

4. Taper turning :

Taper. A **taper** *may be defined as a uniform increase or decrease in diameter of a piece of work measured along its length.*

Refer to Fig. 10.14. The amount of taper in a workpiece is usually *specified by the ratio of the difference in diameters of the taper to its length.* This is termed as the *"capacity"* and it is designated by the letter K.

i.e.,
$$K = \frac{D-d}{l}$$

where, D = Large diameter of taper in mm,
d = Small diameter of taper in mm,
l = Length of tapered part in mm, and
α = Half of taper angle.

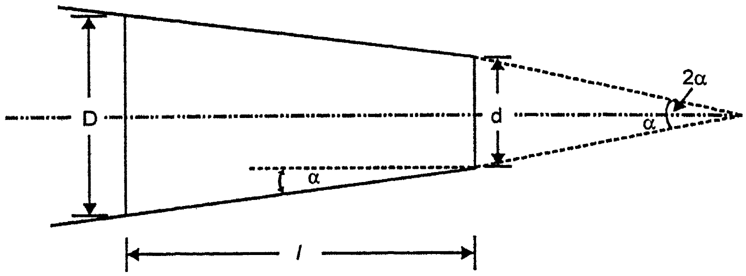


Fig. 10.14.

Taper turning. Taper *turning means to produce a conical surface by gradual reduction in diameter from a cylindrical workpiece.*

— The tapering of a part has wide applications in the construction of machines. Almost all machine spindles have taper holes which receive taper shanks of various tools and work holding devices.

Taper turning methods. Taper turning can be carried out on lathes by the following methods:

1. By setting over the tail stock centre.
2. By swivelling the compound rest.
3. By using a taper turning attachment.
4. By manipulating the transverse and longitudinal feeds of the slide tool simultaneously.
5. By using a broad nose form tool.

1. By setting over the tail stock centre :

- This method is used for *small tapers only* (the amount of setover being limited).
- It is *based upon the principle of shifting the axis of rotation of the workpeice, at an angle to the axis, and feeding the tool parallel to the lathe axis.* The angle at which the axis of rotation of the workpiece is shifted is *equal to half angle of taper.* This is done when the body of the tailstock is made to slide on its base towards or away from the operator by a setover screw as shown in Fig. 10.15.

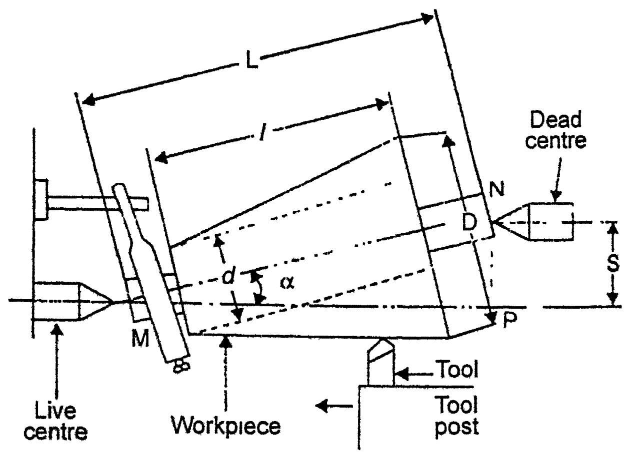


Fig. 10.15. Turning taper by tailstock set-over method.

- By setting tailstock centre to the back (away from the operator) the taper will have bigger diameter towards the tailstock. If the tailstock centre is taken in the front, bigger diameter will be on the headstock side. The reduction in diameter will be twice the offset of tailstock centre if entire length is turned.
- The major **disadvantage** of this method is that the *live and dead centres are not equally stressed and the wear is non-uniform.* Also, the lathe carrier being set at an angle, the *angular velocity of the work is not constant.*

Calculation of setover (S) :

The amount of setover required may be calculated as follows :

From the right angled triangle *MNP* (Fig. 10.15), we have

$$NP \text{ (= setover)}, S = MN \sin(\alpha) = L \sin \alpha$$

For a very small angle, (α) it can be safely considered that

$$\sin \alpha = \tan \alpha$$

i.e., $$\text{setover, } S = L \tan \alpha$$

or $$S = L \times \frac{D-d}{2l} \text{ in mm}$$

$$= \text{Total length} \times \frac{\text{Total taper}}{2 \times \text{taper length}}$$

where, S = The required setover in mm,
D = Large diameter in mm,
d = Small diameter in mm,
L = Total length of work in mm, and
l = Length of tapered portion in mm.

In case the job is to be tapered over its full length, l will be equal to L. Therefore, the setover will be given by :

$$S = \frac{D-d}{2} = \frac{\text{Total taper}}{2}$$

— *The amount of the offset required may be quite accurately set by allowing the tool post to touch the tailstock barrel in the normal and in the offset position. This is accomplished by turning the cross-slide screw when the offset is measured directly by the difference of readings on the micrometer dial. A more accurate reading is obtained by using a dial indicator in conjunction with cross-slide.*

— For accurately setting of the tailstock, *slip gauges are sometimes used.*

2. By swivelling the compound rest :

- It is the best method as it does not affect the centering of the job or centres.
- In this method of taper turning the *workpiece is rotated on the lathe axis and the tool is fed at an angle to the axis of rotation of the workpiece.* The tool mounted on the compound rest is attached to the circular base, graduated in degrees, which may be swivelled and clamped at any desired angle as shown in Fig. 10.16. After the compound rest is set at the desired half taper angle, rotation of the compound slide screw will cause the tool to be fed at that angle and generate a corresponding taper.

- The *setting of compound rest* is done by swivelling the rest at the half taper angle, if this is already known. However, if the diameters of large (D) and small (d) ends are known, the half taper angle can be calculated as follows :

$$\tan \alpha \text{ or } \alpha = \tan^{-1}\left(\frac{D-d}{2L}\right).$$

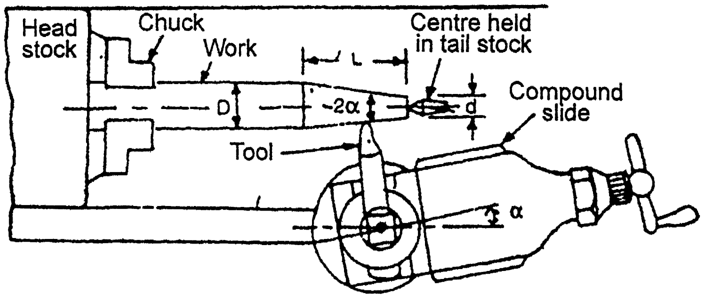


Fig. 10.16. Taper turning.

- Owing to the limited movement of the cross-slide, this method is limited to turn a *short taper ; a small taper* may also be turned.
- This method gives a *low production capacity and poor surface finish because the movement of the tool is completely controlled by hand.*

3. By using a taper turning attachment :

- This method *provides a very wide range of taper.*
- In this method of taper turning a *tool is guided in a straight path set at an angle to the axis of rotation of the workpiece, while the work is being revolved between centres or by a chuck aligned to the lathe axis.*
- As shown in Fig. 10.17 a taper turning attachment essentially consists of a bracket or frame which is attached to the rear end of the lathe bed and supports a *guide bar* pivoted at the centre. The bar is provided with graduations and may be swivelled on either side of the zero graduation and is set at the desired angle with the lathe axis.

The *taper turning attachment is used as follows :*

- The cross-slide is first made free of the lead screw by removing the *binder screw.* The rear end of the cross-slide is then tightened with the guide block by means of a bolt.
- On the engagement of the longitudinal feed, the tool mounted on the cross-slide will follow the angular path, as the guide block slides on the guide bar set at an angle to the both axes.
- The required depth of cut is given by the compound slide which is placed at right angles to the axis of the lathe.
- The guide bar must be set at half taper angle and the taper on the work must be converted in degrees. The maximum angle through which the guide bar may be swivelled is 10° to 12° on either side of the centre line.
- After every cut, the feed to the tool is given by moving the compound rest which is positioned parallel to the cross-slide (*i.e.*, at 90° to the axis of the job).

- The required angle (*i.e.*, angle of swivelling the guide bar) can be found out from the following relation :

$$\tan \alpha = \frac{D - d}{2l} \text{ (all dimensions in mm)}$$

or,

$$\alpha = \tan^{-1}\left(\frac{D - d}{2l}\right) \text{ degrees.}$$

where, D = Larger dia. in mm,

d = Smaller dia. in mm, and

l = Length of taper in mm.

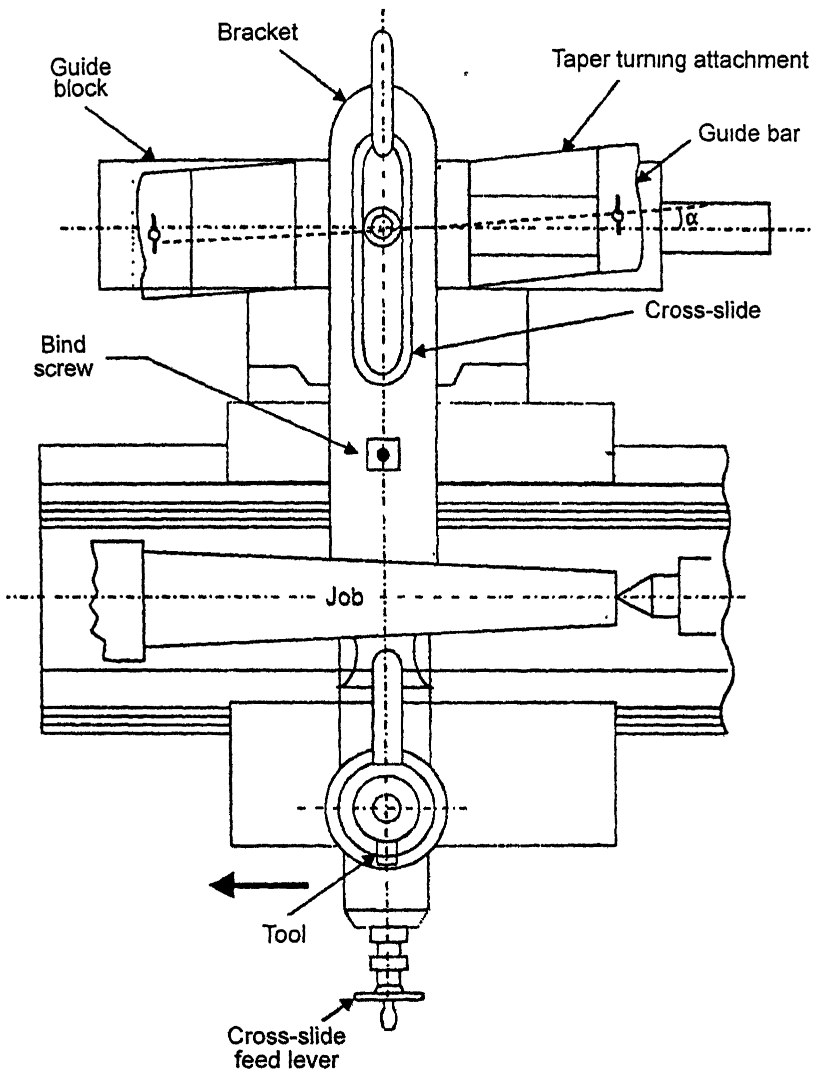


Fig. 10.17. Use of taper turning attachment.

Advantages of using a taper turning attachment :

1. Easy and quick setting.
2. The operator may not be highly skilled.
3. Accurate tapers can be easily obtained in a single setting.
4. Very steep taper on a long workpiece may be turned which is not possible with any other method.
5. It is quite suitable for internal taper as well.
6. It provides a better finish.
7. It ensures an increased rate of production because it is possible to employ longitudinal power feeds easily.
8. During the operation, normal set-up and alignment of the lathe and main parts are not disturbed (as is the case with the other methods).

4. By manipulating the transverse and longitudinal feeds of the slide tool simultaneously :

- Taper turning by manipulation of both feeds is inaccurate and requires skill on the part of the operator.
- It is used for *sharp tapers only.*

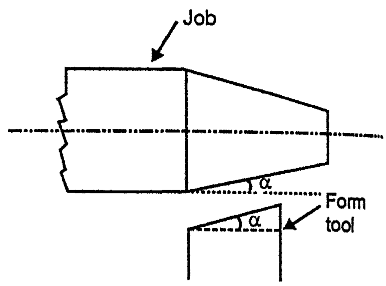


Fig. 10.18. Taper turning by a form tool.

5. By using a broad nose form tool :

- In this method of taper turning (Fig. 10.18) a broad nose tool having straight cutting edge is set on to the work at half taper angle and is fed straight into the work to generate a tapered surface.
- With this method, tapers of short length only can be turned.

6. Drilling. Refer to Fig. 10.19.

- It is an operation of producing a cylindrical hole in a workpiece by the rotating cutting edge of a cutter known as the drill.
- For this operation, the work is held in a suitable device, such as chuck or face plate, as usual, and the drill is held in the sleeve or barrel of the tail stock. The drill is fed by hand by rotating the hand-wheel of the tailstock.

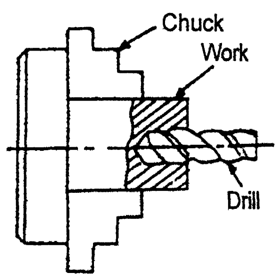


Fig. 10.19. Drilling.

7. Reaming. Refer to Fig. 10.20.

- *Reaming* is the operation which usually follows the earlier operation of drilling and boring in case of those holes in which a *very high grade of surface finish and dimensional accuracy is needed.*
- The tool used in called the *reamer,* which has multiple

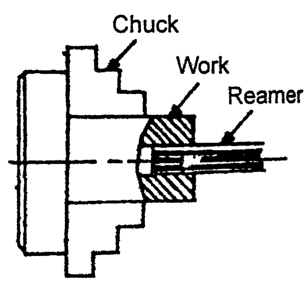


Fig. 10.20. Reaming.

cutting edges. The reamer is held on the tailstock spindle, either direct or through a drill chuck and is held stationary while the work is revolved at very slow speed. The feed varies from 0.5 to 2 mm per revolution.

- For reaming tapered holes, taper reamers are used.

8. Boring. Refer to Fig. 10.21.

- It is the operation of *enlarging and turning a hole produced by drilling, punching, casting or forging.*
- In this operation, as shown in Fig. 10.21, a *boring tool or a bit* mounted on a rigid bar is held in the tool post and fed into the work by hand or power in the similar way as for turning.
- *Boring cannot originate a hole.*

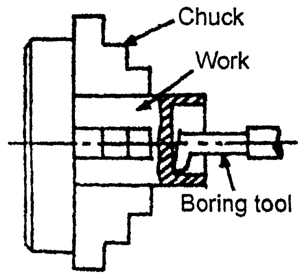


Fig. 10.21. Boring.

9. Undercutting or grooving. Refer to Fig. 10.22.

- It is the process of reducing the diameter of a workpiece over a very narrow surface. It is often done at the end of a thread or adjacent to a shoulder to leave a small margin.
- The work is revolved at half the speed of turning and a grooving tool of required shape is fed straight into the work by rotating the cross-slide screw.

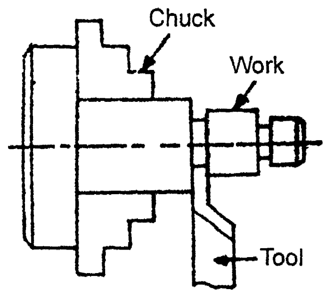


Fig. 10.22. Undercutting.

10. Threading. Refer to Fig. 10.23.

- Threading is an operation of cutting helical grooves on the external cylindrical surface of the workpiece.
- In this operation, as shown in Fig. 10.23, the work is held in a chuck or between centres and the threading tool is fed longitudinally to the revolving work. The longitudinal feed is equal in the pitch of the thread to be cut.

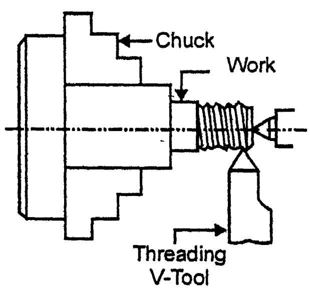


Fig. 10.23. Threading.

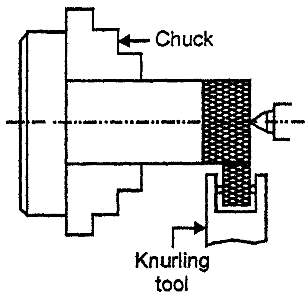


Fig. 10.24. Knurling.

11. Knurling. Refer to Fig. 10.24.

- It is an operation of *embossing a diamond shaped pattern on the surface of a workpiece.*
- The purpose of knurling is to provide an effective gripping surface on a workpiece to prevent it from slipping when operated by hand.

- The operation is performed by a special knurling tool which consists of 1 set of hardened steel rollers in a holder with the teeth cut on their surface in a definite pattern. *The tool is held rigidly on the tool post and the rollers are pressed* against the revolving workpiece to squeeze the metal against the multiple cutting edges, producing depressions in a regular pattern on the surface of the workpiece.
- Knurling is done at the *slowest speed* available in a lathe. Usually the speed is reduced to 1/4th of that of turning, and plenty of oil is flowed on the tool and workpiece.

12. Forming. Refer to Fig. 10.25.

- It is an operation of turning a convex, concave or any irregular shape.
- Form-turning may be accomplished by the following methods : (*i*) Using a forming tool. (*ii*) Combining cross land longitudinal feed, (*iii*) Tracing or copying a template.

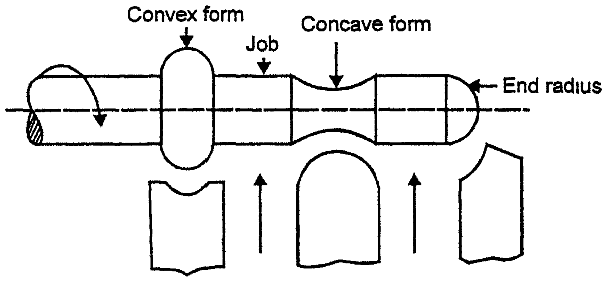


Fig. 10.25. Forming.

10.4.7. Lathe Accessories

The devices employed for handling and supporting the work and the tool on the lathe are called its ***accessories***. The various accessories are enumerated below :

1. Chucks :
   - (*i*) Three jaw universal chuck
   - (*ii*) Four jaw independent chuck
   - (*iii*) Combination chuck
   - (*iv*) Magnetic chuck
   - (*v*) Air or hydraulic chuck
   - (*vi*) Collet.
2. Face plate
3. Angle plate
4. Driving plate
5. Lathe carriers or dogs
6. Lathe centres
7. Lathe mandrels
8. Rests
9. Jigs and fixtures
10. Lathe attachments :
    - (*i*) Stops
    - (*ii*) Grinding attachment
    - (*iii*) Milling attachment
    - (*iv*) Taper turning attachment
    - (*v*) Copying attachment
    - (*vi*) Relieving attachment.

The figures of some accessories are given below :

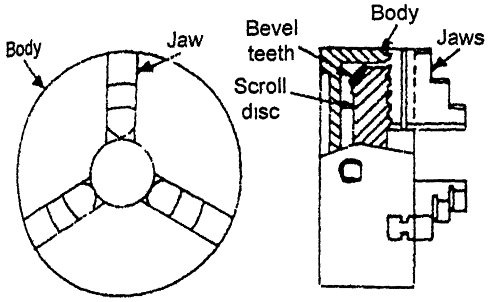


Fig. 10.26. Three jaw chuck.

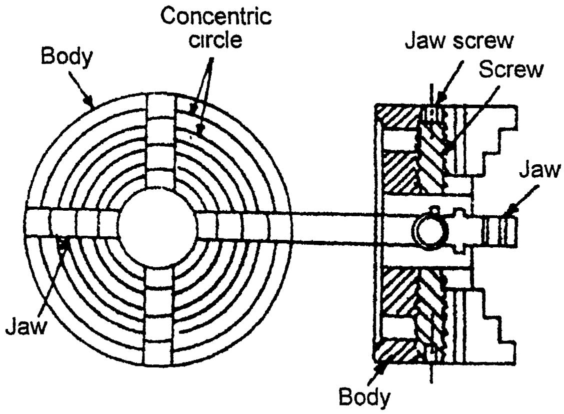


Fig. 10.27. Four jaw chuck.

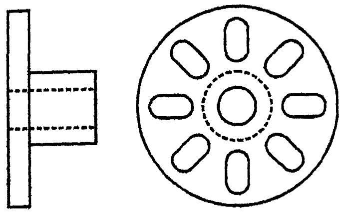


Fig. 10.28. Face plate.

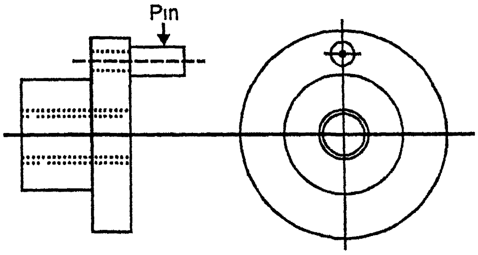
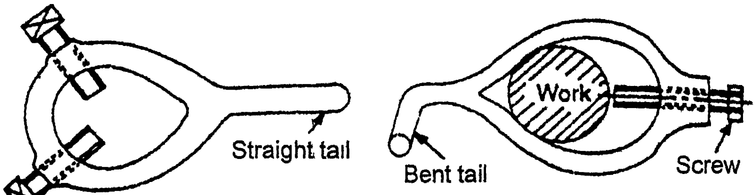


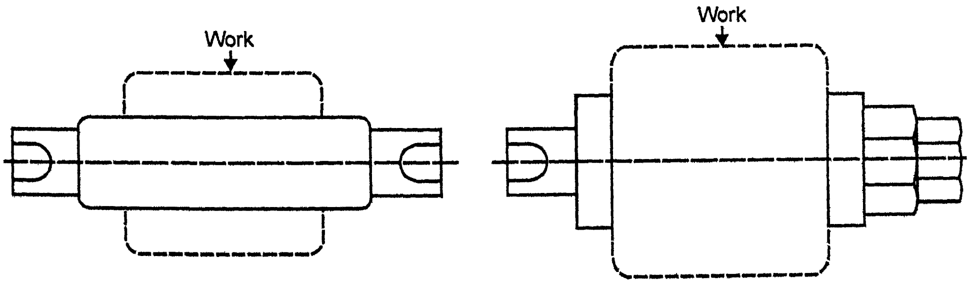
Fig. 10.29. Drive plate.



(a) Straight tail type.

(b) Bent tail type.

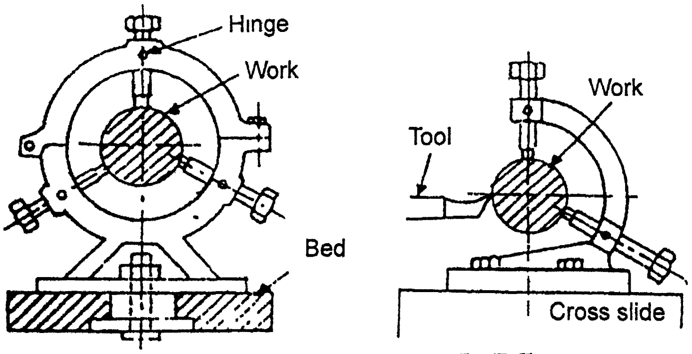
Fig. 10.30. Lathe dog or carrier.



(a) Solid mandrel.

(b) Gang mandrel.

Fig. 10.31. Mandrels.



(a) Steady rest *(b) Follower rest*

Fig. 10.32. Rests.

10.4.8. Eccentric Turning

Although lathe does normal concentric turning, if some parts are required eccentric they can be turned so, on the lathe, as discussed below :

- One of the methods used, is to have *two centres* on the job faces countersunk. The central centre will turn out concentric turning. *Eccentric centre will produce eccentric turning.* The distance of the centres must be *half the eccentricity required for the job.*
- Another method is if the part is to be turned cylindrical around an axis other than central axis, the job can be turned centrally if it can be held in independent jaw chucks so the part to be turned remains central.

10.4.9. Thread Rolling

- Threads are normally cut on a lathe by using threading tools, by use of taps and dies or by milling. In all these methods, the metal chips are formed when the metal is removed from the grooves of the threads. *It breaks the threads at the grooves and the load carrying capacity of the threads is reduced.*
- It is found that instead of cutting threads as above, if the threads are rolled by passing through rollers, we get stronger threads without any metals chips removed.
- Thread rolling method is more economical for the following reasons :
  (*i*) *It does not require skilled labour for operation.*
  (*ii*) *It is faster as compared with other methods.*
  (*iii*) The timings for threading of 50 mm long bar of 2.5 mm diameter by various methods are given below for comparison :
  — *On lathe with threading tools* ...... 20 minutes
  — *On lathe with dies* ...... 3 minutes
  — *On "thread rolling machines"* ...... 5 to 6 seconds.
  (*iv*) There is no danger of the eccentricity of the workpiece.

10.4.10. Cutting Speed, Feed and Depth of Cut

(*i*) **Cutting speed.** *It is the peripheral speed of the work past the cutting tool or the speed, at which the metal is removed by the tool from the work.* It is expressed in metres/min.

$$\text{Cutting speed, } V = \frac{\pi d N}{1000} \text{ m/min.}$$

where, N = r.p.m., and d = diameter in mm.

(*ii*) **Feed.** *It is the distance the tool advances for each revolution of the workpiece. It is expressed in mm/revolution.*

(*iii*) **Depth of cut.** *It is the perpendicular distance measured from the machined surface to the uncut surface of work. It is expressed in mm.*

If, d_1 = Diameter of work before machining, and

d_2 = Diameter of work after machining,

$$\text{Then, Depth of cut} = \frac{d_1 - d_2}{2}$$

10.4.11. Testing of Lathes

Indian standards have laid down specifications for testing lathes upto 800 mm swing over bed by IS : 1878–1961 as given below.

Test 1 : Levelling of machine-longitudinal and transverse directions.

- This is carried out by spirit level of 0.03 to 0.05 mm per metre accuracy and by gauge blocks, to suit the guide ways. The spirit levels are placed on the front and rear guide ways at intervals of 500 mm. The permissible error is 0 02 mm per metre for front guide way.
- The permissible error for rear guide way is 0.01 mm per metre convex and 0.02 mm per metre concave.
- In transverse direction, level is placed on measuring bridge and error of 0.02 mm per metre is allowed but no twist is permitted.

Test 2 : Straightness of saddle is tested by cylindrical mandrel 600 mm long and dial gauge. If dial indicator is placed on the saddle, the mandrel, should not show a variation of more than 0.02 mm in its length.

Test 3 : Alignment of both centres in vertical plane is checked by dial indicator on saddle above the mandrel. It is essential that the lathe has run sufficiently to heat the main spindle bearings to normal working temperature. The permissible error is 0.02 mm.

Test 4 : Parallelism of spindle to saddle movement in both horizontal and vertical planes is measured by dial indicator and mandrel. The error allowed is 0.02 mm for every 300 mm.

Test 5: Movement of upper slide paralleled with main spindle in the vertical plane. The permissible error is 0.03 mm for every 100 mm.

Test 6 : True running of locating cylinder of main spindle by dial gauge within 0.01 mm.

Test 7 : True running of head stock center within 0.01 mm accuracy by dial gauge.

Test 8 : Parallelism of tail stock guide ways with movement of carriage in both planes. The permissible error is 0.04 mm for turning lengths up to 5 metres and 0.05 mm for shorter turnings. For every 1,000 mm the error should not exceed 0.03 mm.

Test 9: Pitch accuracy of lead screw should be within 0.03 mm between any 2 threads at a maximum distance of 300 mm from each other.

Test 10 : Axial slip of lead screw should be within 0.01 mm in each direction by dial gauge.

Test 11: Alignment of lead screw bearings with respect to each other in both planes is to be within 0.1 mm by dial gague.

Test 12 :Working accuracy of machine and cylindrical turning is to be within 0.01 mm.

Test 13 : Working accuracy for facing is to be within 0.02 mm over the diameter of the test piece.

Test 14 : Pitch accuracy of thread cut is to be within 0.02 mm on 50 mm length when the workpiece is held between the centres and threads are cut.

The following **additional tests** are also carried out if possible :

(*a*) *Alignment of lead screw bearings with split nut in both planes within* + 0.15 mm.

(*b*) *Parallelism of tail stock sleeve to saddle movement within* 0.01 mm.

(*c*) *Parallelism of tail stock sleeve taper socket to saddle movement.*

(*d*) *Axial slip of main spindle and true running of shoulder face of spindle nose.*

10.5. DRILLING MACHINES

10.5.1. Introduction

- Drilling machine is one of the simplest, moderate and accurate machine tool used in production shop and tool room. It consists of a ***spindle*** which imparts rotary motion to the drilling tool, or mechanism for feeding the tool into the work, a ***table*** on which the work rests and a ***frame***. It is considered as *a single purpose machine tool since its chief function is to make holes.* However, it can and does perform operations *other than drilling also.*
- ***Drilling*** is a *process of making hole or enlarging a hole in an object by forcing a rotating tool called "Drill".*

10.5.2. Specifications of a Drilling Machine

A drilling machine is *specified* as follows (Refer to Fig. 10.33) :

1. Size of the drilling machine table.
2. Largest bit the machine can hold.
3. Maximum size of the hole that can be drilled.
4. Maximum size of the workpiece that can be held.
5. Power of the motor, spindle speed or feed.

Specifically, the various *types of drilling machines are specified as follows :*

- **Portable drilling machine.** *Maximum diameter of drill which can be held.*
- **Sensitive and upright drilling machines.** *The diameter of the largest workpiece that can be drilled.*

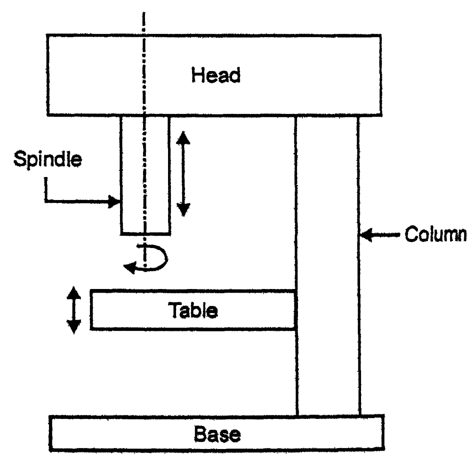


Fig. 10.33. Block diagram of a drill press.

- **Radial drilling machine.** *The length of the arm and column diameter.*
- **Multiple sprindle drilling machine.** *The drilling area, the size and number of holes a machine can drill.*

10.5.3. Operations Performed

Although drill press is mainly meant for drilling operation, it can also be used for performing the following operations : Refer to Fig. 10.34.

1. **Reaming.** It is an *operation of finishing an existing drilling hole.* The tool used is reamer.

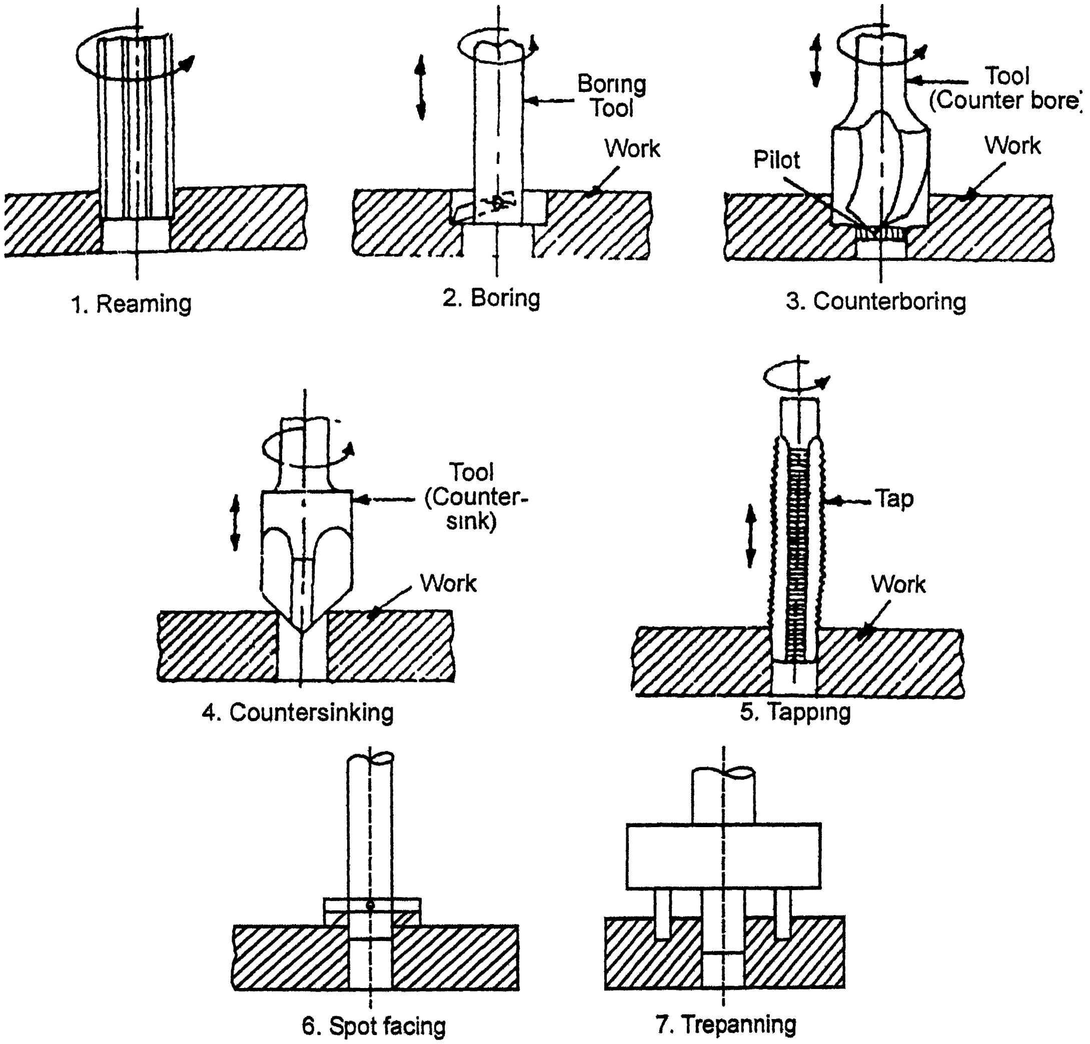


Fig. 10.34.

2. **Boring.** It is an *operation of enlarging an existing hole.*
3. **Counter boring.** It is an *operation of enlarging a drilled hole partially, that is for*

a specific length.

4. **Countersinking.** It is an *operation of forming a conical shape at the end of a drilled hole.*
5. **Tapping.** It is an *operation in which external threads are cut in the existing hole.*
6. **Spot facing.** It is the *operation of smoothing and squaring the surface around a hole for the seat for the nut or the head of a screw.* A counter bore or a special spot facing tool may be employed for this purpose.
7. **Trepanning.** It is the operation of *producing a hole by removing the metal along the circumference of a hollow cutting tool.* This operation is performed for *producing large holes.*

10.5.4. Classification of Drilling Machines

Some of the common drilling machines used in production work are :

1. **Hand drill-power operated.** It is used to produce holes (small) where it is not possible to bring the workpiece requiring the hole onto the work table of a drilling machine.
2. **Bench drilling machine.** It is used to drill hole from 1.5 mm to 15 mm diameter.
3. **Upright drilling machine.** It is mounted on floor and is used to drill holes upto 25 mm.
4. **Radial drilling machine.** It is used when a drilling operation is to be performed on heavy or bulk workpiece. Also used where the workpiece cannot be adjusted to locate the point of drilling.
5. **Gang drilling machine.** It is used where a series of operations have to be performed like drilling, boring, reaming, tapping etc.
6. **Multispindle drilling machines.** It is used whenever a number of holes are to be drilled on a workpiece.

Figs. 10.35, 10.36, 10.37 show block diagrams of a bench drilling machine, upright drilling machine and radial drilling machine respectively.

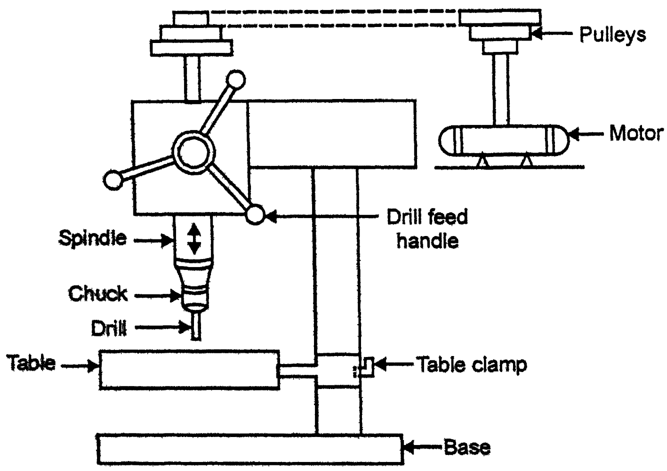


Fig. 10.35. Bench drilling machine.

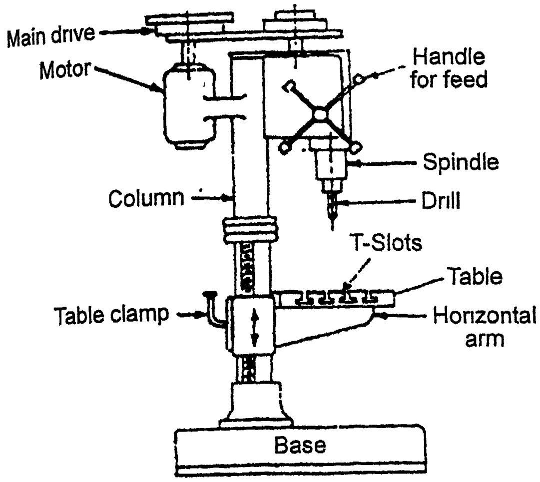


Fig. 10.36. Upright drilling machine.

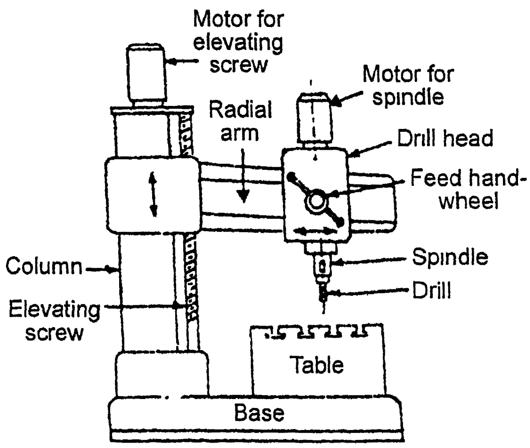


Fig. 10.37. Radial drilling machine.

Figs. 10.38, 10.39 show a twist drill and its nomenclature respectively.

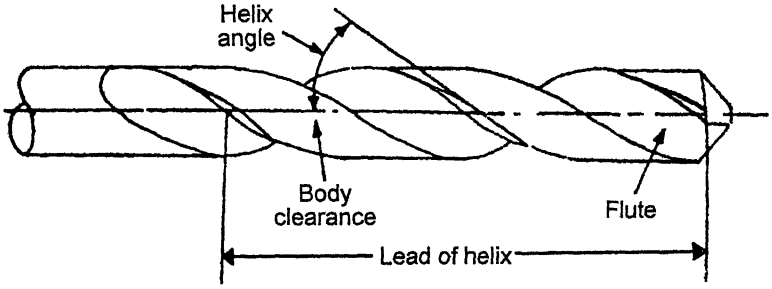


Fig. 10.38. Twist drill.

10.5.5. Cutting Speeds and Feeds

- The *cutting speed* depends upon the following factors :
  (*i*) The type of material being drilled.
  (*ii*) Cutting tool material.
  (*iii*) The quality of hole desired.
  (*iv*) The efficient use of cutting fluid.
  (*v*) The way in which the work is set up or held.
  (*vi*) The size and type of drilling machine.
- ***Feed of the drill*** is the *axial distance the drill advances into the work piece for each complete revolution of the drill and is given in mm/rev.* The correct feeds for different sizes of drill are given below :

Drill size, mm	**Feed, nun/rev**
3.2 and less	0.025—0.050
3.2 to 6.4	0.050—0.10
6.4 to 12.7	0.10—0.18
12.7 to 25.4	0.18—0.38
25.4 and large	0.38—0.64

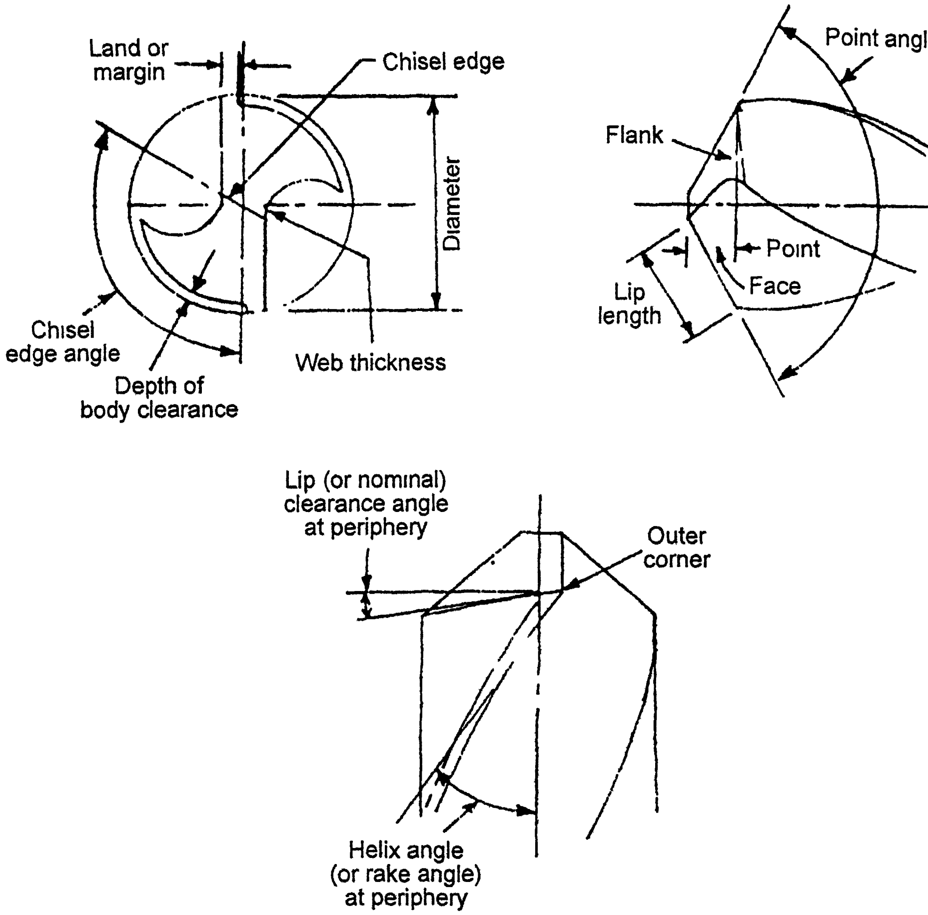


Fig. 10.39. Twist drill nomenclature.

10.5.6. Work Holding Devices

The type of work holding device used on drilling machines depends upon the shape and size of the workpiece, the required accuracy and the rate of production. Some of the work holding devices are listed below :

1. Machine vice
2. V-blocks
3. Strap champs and T-bolts
4. Drilling jigs
5. Angle plate.

10.5.7. Drill Holding Devices

The drill holding devices are enumerated below :

1. Spindle;
2. Sleeve;
3. Socket;
4. Drill chucks.

10.5.8. Drilling Machine Tools

Drilling machine tools include the following :

1. Flat drill	2. Straight drill	3. Twist drill
4. Taper shank core drill	5. Oil tube drill	6. Centre drill
7. Reamer	8. Centre punch	9. Drift
10. Hammer.		

10.6. SHAPING MACHINE (SHAPER)

10.6.1. Introduction

Refer to Fig. 10.40.

- A *shaper is a reciprocating type of machine tool intended primarily to produce horizontal, vertical or inclined flat surfaces (upto 1000 mm long).*
- In the shaper, the cutting tool has a reciprocating motion, and *it cuts only during the forward stroke only.*
- The work is held in a vice bolted to the worktable. The *regular feed is obtained by moving the work table automatically at right angles to the direction of the cutting tool and the tool head gives downward feed at right angles to the regular feed or at any other angle as desired.*

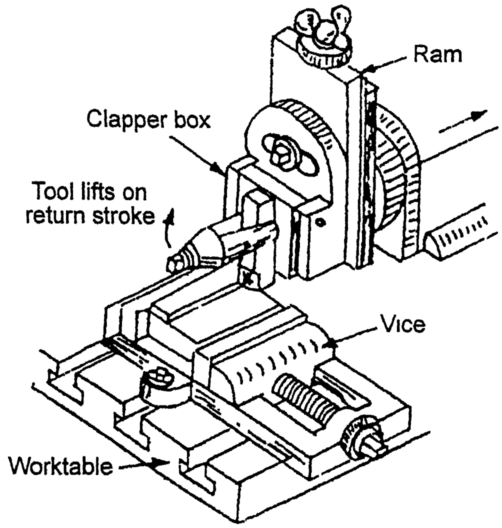


Fig. 10.40. Shaper.

10.6.2. Classification of Shapers

The shapers are *classified* as follows :

1. *According to the type of mechanism used for giving reciprocating motion to the ram:*
   (*i*) Crank type (*ii*) Geared type
   (*iii*) Hydraulic type.
2. *According to the position and travel of ram :*
   (*i*) Horizontal type (*ii*) Vertical type
   (*iii*) Travelling head type.
3. *According to the type of cutting stroke :*
   (*i*) Push type (*ii*) Draw type.
4. *According to the type of design of the table :*
   (*i*) Standard shaper (*ii*) Universal shaper.

10.6.3. Principal Parts

Refer to Fig. 10.41. The principal parts of a shaper are described briefly below :

1. Base :

- It is made of cast iron to resist vibration and takes up high compressive load.

- It is so designed that it can take up the entire load of the machine and the forces set up by the cutting tool over the work.

2. Column :

- It is a box like casting mounted upon the base.
- It encloses ram driving mechanism.
- It is provided with guideways on its top to enable the ram to slide on it.

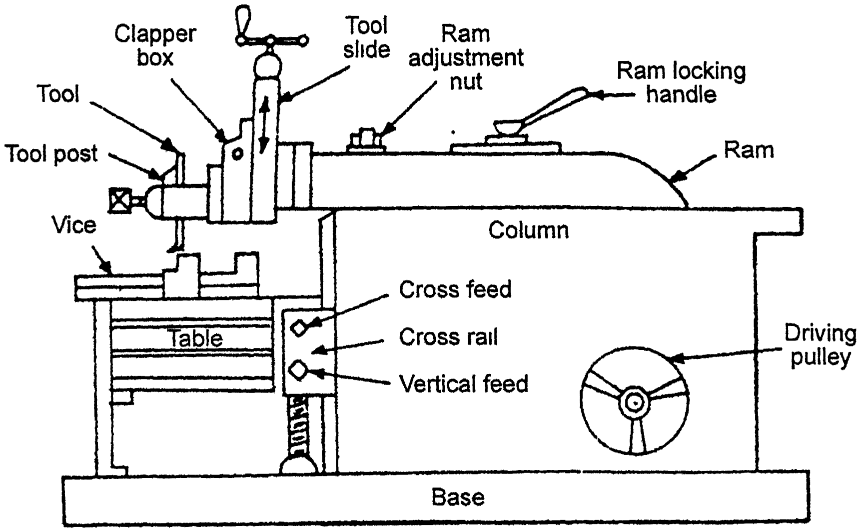


Fig. 10.41. Principal parts of a shaper.

3. Ram :

- It ia a reciprocating member which reciprocates on the guideways provided above the column.
- It carries a tool-slide on its head and a mechanism for adjusting the stroke length.

4. Cross-rail :

- It is mounted on the front vertical guideways of the column.
- It has two parallel guideways on its top in the vertical plane that are perpendicular to the ram axis. The table may be raised or lowered to accommodate different sizes of jobs by rotating an elevating screw which causes the cross-rail to slide up and down on the vertical face of the column.

5. Table :

- It is made of cast iron and is rectangular in shape.
- It has T-slots on its top surface.
- The table can be moved upward, downward or sideward with the help of elevating screws and other feed handle.

10.6.4. Specifications of a Shaper

The shaper is *specified* as follows :

1. Maximum length of the stroke (in mm).

2. Size of the table, *i.e.*, length, width and depth of the table.
3. Maximum horizontal and vertical travel of the table.
4. Maximum number of strokes per minute.
5. Type of quick return mechanism.
6. Power of the drive motor.

10.6.5. Operations Performed

On a standard shaper the following operations can be performed :

(*i*) Machining of *vertical surfaces*
(*ii*) Machining of *horizontal surfaces*
(*iii*) Machining of *angular surfaces*
(*iv*) Machining of *curved surfaces*
(*v*) Machining of *irregular surfaces*
(*vi*) Machining of *slots and keyways.*

10.6.6. Tools Used

Following tools are used :

(*i*) Try square and square head of combination set
(*ii*) Micrometer
(*iii*) Surface gauge
(*iv*) Sine bar
(*v*) Dial test indicator.

- The cutting tools used in shapers are similar to those used in lathe work *except for side and front clearances.*
- Shaper tools have *less* side and front clearance because the work feeds into it on the return stroke, whereas the lathe tool is constantly feeding into the work. For best results these angles should not exceed 4° and be less than 2°.

10.7. PLANING MACHINE (PLANER)

10.7.1. Introduction

Refer to Fig. 10.42.

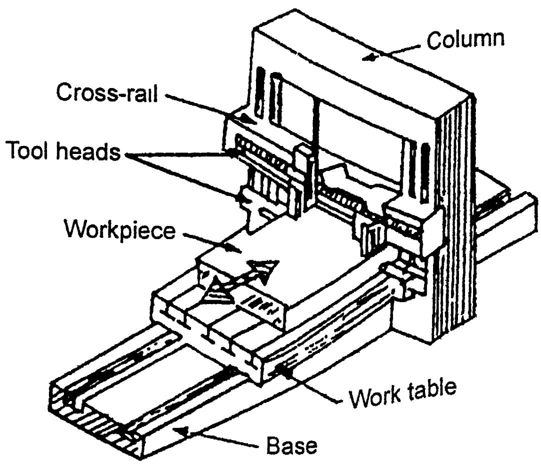


Fig. 10.42. Planer.

- The planning machine (*planer*) is a machine tool *used in the production of flat surfaces on workpieces too large or too heavy to hold in a shaper.*

- In this machine, the table called *PLATEN, on which the work is securely fastened, has a reciprocating motion.*
- The *tool head is automatically* fed horizontal in either direction along the heavily supported cross-rail over the work, and automatic downward feed is also provided.

10.7.2. Comparison between Planer and Shaper

Comparison between a planer and a shaper is given in the Table 10.1 below :

TABLE 10.1
Comparison between Planer and Shaper

S.No.	*Planer*	*Shaper*
1.	Heavier, more rigid and costlier machine.	A comparatively lighter and cheaper machine.
2	Requires more floor area.	Requires less floor area.
3	Work reciprocates horizontally.	Tool reciprocates horizontally.
4.	Tool is stationary during cutting.	Work is stationary during cutting.
5.	Heavier cuts and coarse feeds can be employed.	Very heavy cuts and coarse feeds cannot be employed.
6.	Work setting requires much of skill and takes a longer time.	Clamping of work is simple and easy.
7	Several tools can be mounted and employed simultaneously, usually four as a maximum, facilitating a faster rate of production.	Usually one tool is used on a shaper.
8.	Used for machining large size workpieces.	Used for machining small size workpieces comparatively.

10.7.3. Types of Planer

The various types of planers commonly used are :

1. Double housing (standard) planer.
2. Open side planer.
3. Pit planer.
4. Edge or plate planer.
5. Divided table planer.

10.7.4. Principal Parts of a Planer

The principal parts of a double housing planer are described below :

1. Bed :

- It is a big cast iron structure.
- The upper part of the bed is provided with precision Vee-type guide ways on which the table slides.

2. Table :

- It is made of cast iron and its top surface (flat) is machined accurately.
- It reciprocates along the ways of the bed and supports the work.

- Its top surface is provided with slots to clamp the workpieces.
- It may be driven by rack and gear, by rack and double helical gear or by hydraulic system.

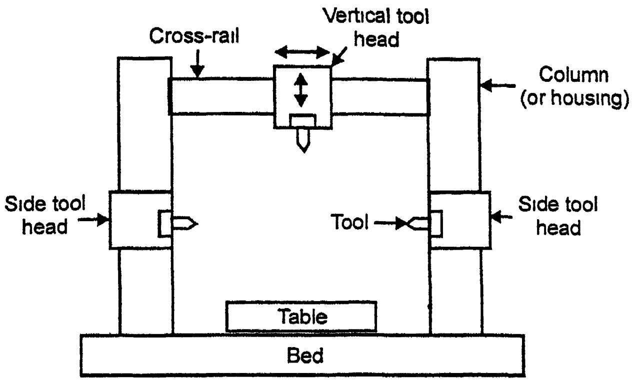


Fig. 10.43. Double housing or standard planer.

3. Column or Housing :

- The columns or housings are rigid column-like castings placed on each side of the bed.
- The front vertical surface of the column has guide ways to enable movement of the cross-rail vertically up and down.

4. Cross-rail :

- It is mounted on the precision machined ways of the two housings.
- It may be raised or lowered on the housings to accommodate work of differents heights on the table and to allow for the adjustment of the tools.

5. Tool heads :

These are mounted on the cross-rail or housings by means of a saddle which slides along the rail or housing ways. The saddle may be made to move transversely on the cross-rail to give cross feed.

10.7.5. Size of a Planer

- The size of a standard planer is specified by the *size of the largest rectangular solid that can reciprocate under the tool.*
- Double housing planers range from 750 mm × 750 mm × 2.5 m as the smallest and upto 3000 mm × 3000 mm × 18.25 m as the largest size.
- In addition to the basic dimensions, other particulars given below also need to be stated for specifying the planer completely :
  — Number of speeds and feeds available
  — Power input
  — Floor space required
  — Net weight of the machine
  — Type of drive etc.

10.7.6. Standard Clamping Devices

The following are the standard clamping devices used for holding most of the work on a planer table :

1. Heavy duty vices
2. T-bolts and clamps
3. Step blocks, clamps, T-bolts
4. Poppets or stop pins and the dogs
5. Angle plates
6. Planer jacks
7. Planer centres
8. V-blocks
9. Stops.

10.7.7. Planer Operations

The common planer operations performed in planer are as follows :

1. Planing horizontal surfaces
2. Planing vertical surfaces
3. Planing curved surfaces
4. Planing slots and grooves
5. Planing at an angle and machining dove-tails.

10.8. MILLING MACHINE

10.8.1. General Aspects

- The milling machine is *a machine tool in which metal is removed by means of a revolving cutter with many teeth, each tooth having a cutting edge which removes metal from a workpiece.*
- The work is supported by various methods on the worktable, and may be fed to the cutter, longitudinally, transversely or vertically.
- A great variety of work may be done on a milling machine.
- This machine is perhaps next to the lathe in importance.

Generally there are two types of milling process, namely :

(*i*) Upmilling (or conventional) process

(*ii*) Downmilling (or climb) process.

— In **upmilling process** (Refer to Fig. 10.44), *the workpiece is fed opposite to the cutter's tangential velocity.*

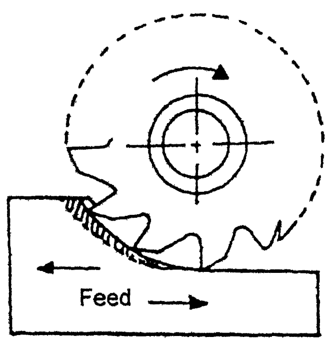


Fig. 10.44. Upmilling process.

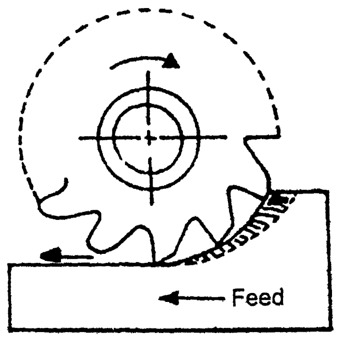


Fig. 10.45. Downmilling process.

— In **downmilling process** (Refer to Fig. 10.45), *the workpiece is fed in the same direction as that of the cutter's tangential velocity.*

Fig. 10.46 shows the nomenclature of a milling cutter.

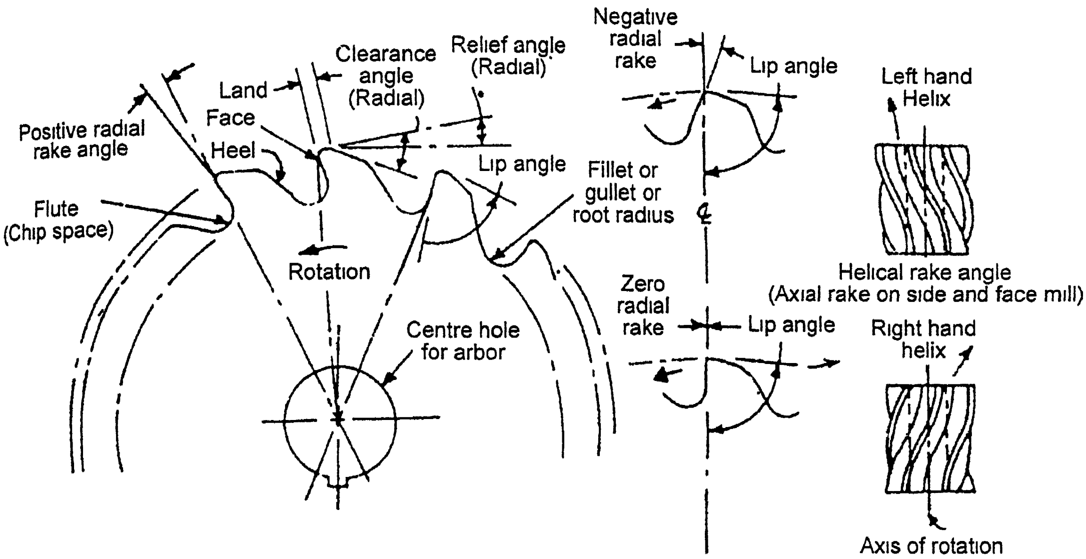


Fig. 10.46.

10.8.2. Specifications of a Milling Machine

The following are the specifications of a *column and knee type milling machine :*

1. Width and length of the table.
2. Maximum distance the knee can travel.
3. Maximum longitudinal movement and cross feed of the table.
4. Number of spindle speeds.
5. Power of the main drive motor.

10.8.3. Types of Milling Machines

According to the general design of the milling machine, the usual *classifications* of the milling machine are :

1. *Column and knee type :*
   (*i*) Plain milling machine (*ii*) Plain milling machine
   (*iii*) Universal milling machine (*iv*) Omniversal milling machine
   (*v*) Vertical machine.
2. *Manufacturing or fixed bed type :*
   (*i*) Simplex milling machine (*ii*) Duplex milling machine
   (*iii*) Triplex milling machine.
3. *Planer type :*
4. *Special type :*
   (*i*) Rotary table milling machine (*ii*) Drum milling machine
   (*iii*) Planetary milling machine
   (*iv*) Pantograph, profiling and tracer controlled milling machine.

10.8.4. Main Parts of a Horizontal Milling Machine

Refer to Fig. 10.47. The main parts of a horizontal milling machine are briefly described below :

1. Base :

- It is a heavy casting on which column and other parts are mounted.
- It may be bolted to the floor strongly.

2. Column :

- There are guideways on the front face of the column, on which the knee slides.
- It houses power transmission units such as gears, belt drives and pulleys to give rotary motion to the arbor. The drive mechanisms are also used to give automatic feed to the handle and table.

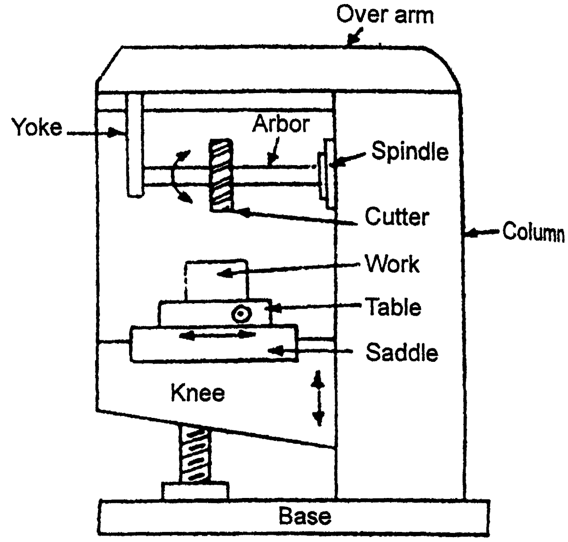


Fig. 10.47. Horizontal milling machine.

3. Knee :

- It supports the saddle, table, workpiece and other clamping devices.
- It moves on guideways of the column.
- It resists the deflection caused by the cutting forces on the workpiece.

4. Saddle :

- It is mounted on the knee and can be moved by a handwheel or by power.
- The direction of travel of the saddle is restricted to be towards or away from the column face.

5. Table :

- It is mounted on the saddle and can be moved by a handwheel or power.
- Its top surface is machined accurately to hold the workpiece and other holding devices.
- It moves perpendicular to the direction of saddle movement.

6. Arbor :

- Its one end is attached to the column and the other end is supported by an over arm.
- It *holds and drives different types of milling cutters.*

7. Spindle :

- It gets power from gears, belt drives, to drive the motor.
- It has provision to add or remove milling cutters onto the arbor.

10.8.5. Types of Milling Cutters

Common types of milling cutters are enumerated below :

1. Plain milling cutters	2. Side milling cutters
3. End milling cutters	4. Face milling cutters
5. Metal slitting cutters	6. Angle milling cutters
7. Formed milling cutters	8. Woodruff-key milling cutters
9. T-slot milling cutter	10. Fly cutter.

10.8.6. Milling Operations

The milling operations are *classified* as follows :

1. Plain or slab milling	2. Face milling
3. Angular milling	4. Form milling
5. Straddle milling	6. Gang milling
7. End milling	8. T-slot milling
9. Dove-tail milling	10. Jaw milling
11. Involute gear cutting.	

1. Plain or slab milling. Plain milling is used to *machine flat and horizontal surfaces* (Fig. 10.48). Here plain milling cutter is used, which is held in the arbor and rotated. The table is moved upwards to give the required depth of cut.

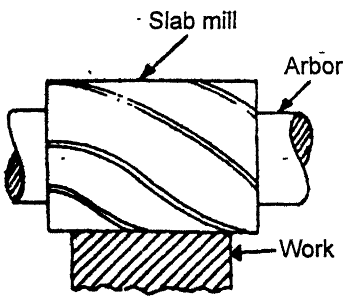


Fig. 10.48. Plain or slab milling.

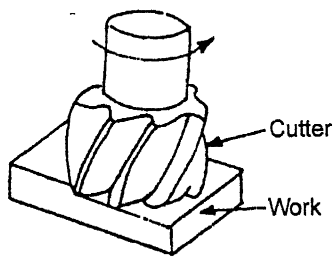


Fig. 10.49. Face milling.

2. Face milling. This milling process (Fig. 10.49) is used for machining a flat surface which is at right angles to the axis of the rotating cutter. The cutter used in this operation is the *face milling cutter.*

3. Angular milling. In angular milling, an angle milling cutter is used (Fig. 10.50). The cutter used may be a *single* or *double* angle cutter, depending upon whether a single surface is to be machined or two mutually inclined surfaces simultaneously.

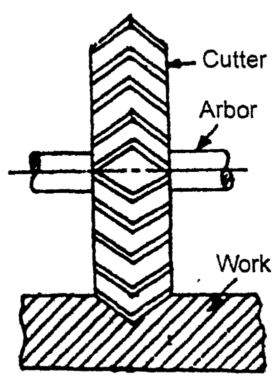


Fig. 10.50. Angular milling.

4. Form milling. This milling process (Fig. 10.51) is used for machining those surfaces which are of *irregular shapes*. The form milling cutter used has the shape of its cutting teeth conforming to the profile of the surfaces to be produced.

5. Straddle milling Refer to Fig. 10.52. Stradding milling is an operation in which a pair of *side milling cutters* is used for machining two parallel vertical surfaces of a workpiece simultaneously. The distance between the cutters is adjusted by the spacers. This process is used to mill *square and hexagonal surfaces.*

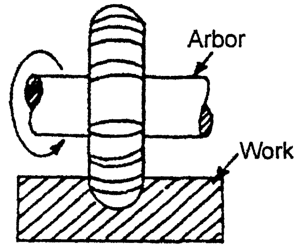


Fig. 10.51. Form milling.

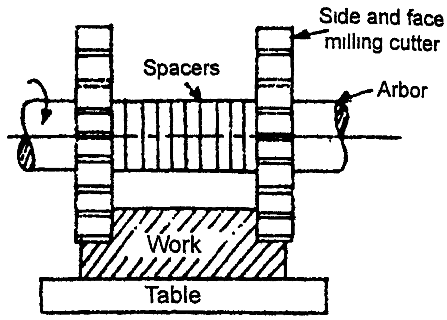


Fig. 10.52. Straddle milling.

6. Gang milling. Gang milling (Fig. 10.53) is the name given to a milling operation which involves the use of a *combination of more than two cutters,* mounted on a common arbor, for milling a number of flat horizontal and vertical surfaces of a workpiece simultaneously This method *saves much of machining time* and is widely used in *repetitive work.* The cutting speed of a gang of cutters is calculated from the cutter of the largest diameter.

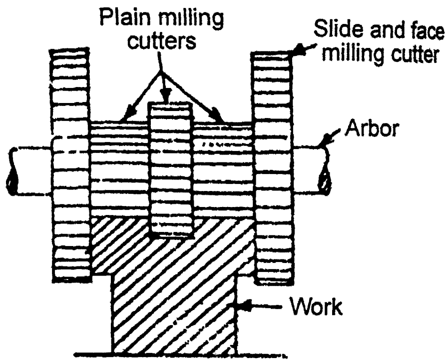


Fig. 10.53. Gang milling.

7. End milling. Refer to Fig. 10.54. It is an operation of producing narrow slots, grooves and keyways using an end mill cutter. The mill tool may be attached to the vertical spindle for milling the slot. Depth of cut is given by raising the machine table.

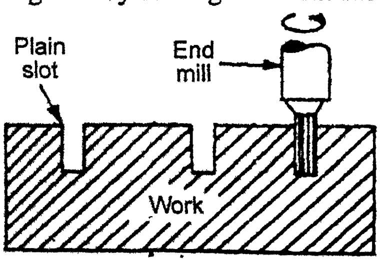


Fig. 10.54. End milling.

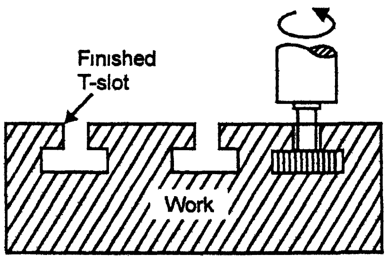


Fig. 10.55. T-slot milling.

8. T-slot milling. Refer to Fig. 10.55. In this milling operation, first a plain slot is cut on the workpiece by a side and face milling cutter. Then the T-slot cutter is fed from the end of the workpiece.

9. Dove-tail milling. Refer to Fig. 10.56. In this milling operation, the end of the cutter is shaped to the required dove-tail angle. The cutter is passed from one end of the workpiece to the other end.

10. Saw milling. Refer to Fig. 10.57. It is an operation of producing narrow grooves and slots on the workpiece. A slitting saw is used for saw milling.

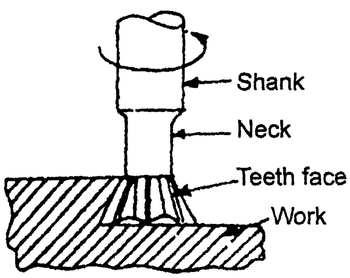


Fig. 10.56. Dove-tail milling.

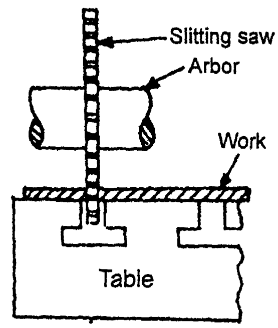


Fig. 10.57. Saw milling.

11. Involute gear cutting. Gear milling operation, often referred as *gear cutting* involves cutting of different types of gears on a milling machine. For this, either an *end mill cutter or a form relieved cutter* is used, which carries the profile on its cutting teeth corresponding to the required profile of the gap between gear teeth.

Fig. 10.58 shows involute gear cutting operation. Shape of the cutter teeth resembles the involute profile. Gear blank is, indexed after cutting each tooth.

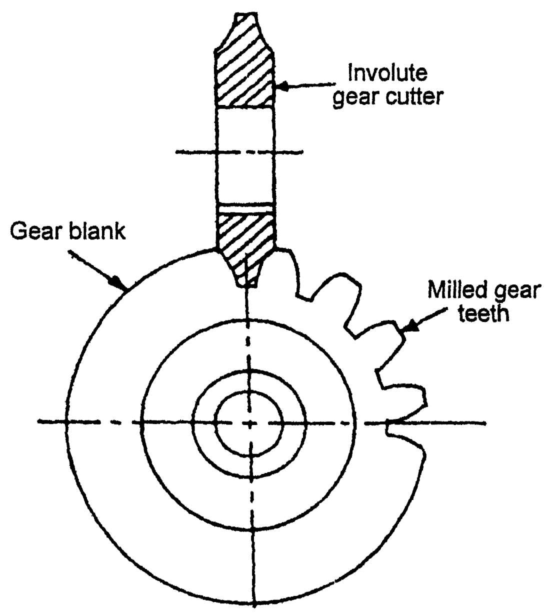


Fig. 10.58. Involute gear cutting.

10.8.7. Cutting Speed, Feed and Depth of Cut

Cutting speed. The cutting speed of a milling cutter is the *distance travelled per minute by the cutting edge of the cutter.* It is expressed in metres per minute.

In other words, $V = \dfrac{\pi d N}{1000}$ metres per min.

where, V = The cutting speed in m/min.,

d = The diameter of the cutter in mm, and

N = The cutter speed in r.p.m.

Feed. The feed in a milling machine is defined as *the rate at which the workpiece advances under the cutter.* The feed is expressed by the following three methods :

(*i*) Feed per tooth (mm per tooth of the cutter);

(*ii*) Feed per revolution (mm per revolution of the cutter);

(*iii*) Feed per minute (mm per minute).

10.9. COMPARISON OF MACHINING PROCESSES

The comparison of various machining processes is given in Table 10.2 below ·

TABLE 10.2

Comparison of Machining Processes

Process	*Advantages*	*Limitations*
1. Turning	(*i*) Most versatile machine capable of producing external and internal circular profiles and flat surfaces (*ii*) All types of materials can be turned. (*iii*) Low tooling cost. (*iv*) Large components can be turned.	(*i*) Low production rate. (*ii*) Requires skilled labour. (*iii*) Close tolerances and fine finish cannot be achieved.
2. Drilling	(*i*) Most suitable for producing round holes of various sizes. (*ii*) Inexpensive tooling and equipment. (*iii*) High production rate. (*iv*) Machine can be used for reaming and tapping.	(*i*) Basically a rough machining operation. (*ii*) Requires semi-skilled labour.
3. Boring	(*i*) Variety of internal circular profiles can be obtained. (*ii*) All types of materials can be bored. (*iii*) Low tooling cost. (*iv*) Large components can be bored. (*v*) Provides better dimensional control and surface finish.	(*i*) Low production rate. (*ii*) Requires skilled labour. (*iii*) Suitable for internal profiles only. (*iv*) Stiffness of boring bar is an important consideration.
4. Milling	(*i*) Versatile operation with wide variety of toolings and attachments. (*ii*) Variety of shapes including flats, slots and contours can be obtained. (*iii*) Suitable for low and medium production rate. (*iv*) Better dimensional control and surface finish.	(*i*) Tooling relatively more expensive. (*ii*) Requires skilled labour.

5. *Shaping*	(*i*) Suitable for low production rate. (*ii*) Suitable for producing flat and contour profiles on small size workpieces. (*iii*) Low tooling and equipment cost.	(*i*) Large size workpieces cannot be used. (*ii*) Requires skilled labour. (*iii*) Only simple profiles can be obtained. (*iv*) Close tolerance and fine finish cannot be obtained.
6. *Planning*	(*i*) Suitable for low production rate. (*ii*) Suitable for producing flat and contour profiles on large workpieces. (*iii*) Low tooling cost.	(*i*) Only simple profiles can be obtained. (*ii*) Requires skilled labour. (*iii*) Close tolerance and fine finish cannot be obtained.

10.10. CNC MACHINES AND CAD/CAM

A. CNC MACHINES

10.10.1. Introduction to Modern Machine Tools

Newer machine tools have been built to absorb newer machining technologies to cope with newer and tougher materials. New technologies include Ultrasonic Machining (USM), Electro-Chemical Machining (ECM), Laser Beam Machining (LBM) etc. Besides this the advancement in electronics and application of computer in the machine tools have brought in a significant and revolutionary change in the machine tool control concept. This has given birth to an entirely new generation of machine tools. Numerically Controlled (NC) machine tools are highly flexible and are economical for producing a single or a large number of parts. **Numerical Control, NC** can be defined simply as *control by numbers*. A machine tool having a *dedicated computer to help prepare the program and control some or all of the operations of the machine tool is* called **Computer Numerical Control** (CNC) *machine tool.*

10.10.2. NC Machines

10.10.2.1. Introduction

NC machines assimilate a method of automation, where automation of medium and small volume production is done by some controls under the instructions of a program. The definition of NC (Numerical Control) as given by EIA (Electronic Industries Association) is as under :

"A system in which actions are controlled by the direct insertion of numerical data at some point. The system must automatically interpret at least some portion of this data."

In NC machines, the input information for controlling the machine tool motion is provided by means of *punched tapes* or *magnetic tapes in a coded language.*

10.2.2. Working of NC Machine Tool

Fig. 10.59 shows the working sequence of a NC machine tool viz-a-viz operator controlled machine tool.

- The first two steps, component drawing and process planning are similar in both operator controlled and NC machine tools.

- In the operator controlled machine tools, the operator controls the cutter position during manufacture and also makes necessary adjustments and corrections to produce the desired component.
- However, in NC machine tool the *operator is replaced by the data processing part of the system and the control unit.*

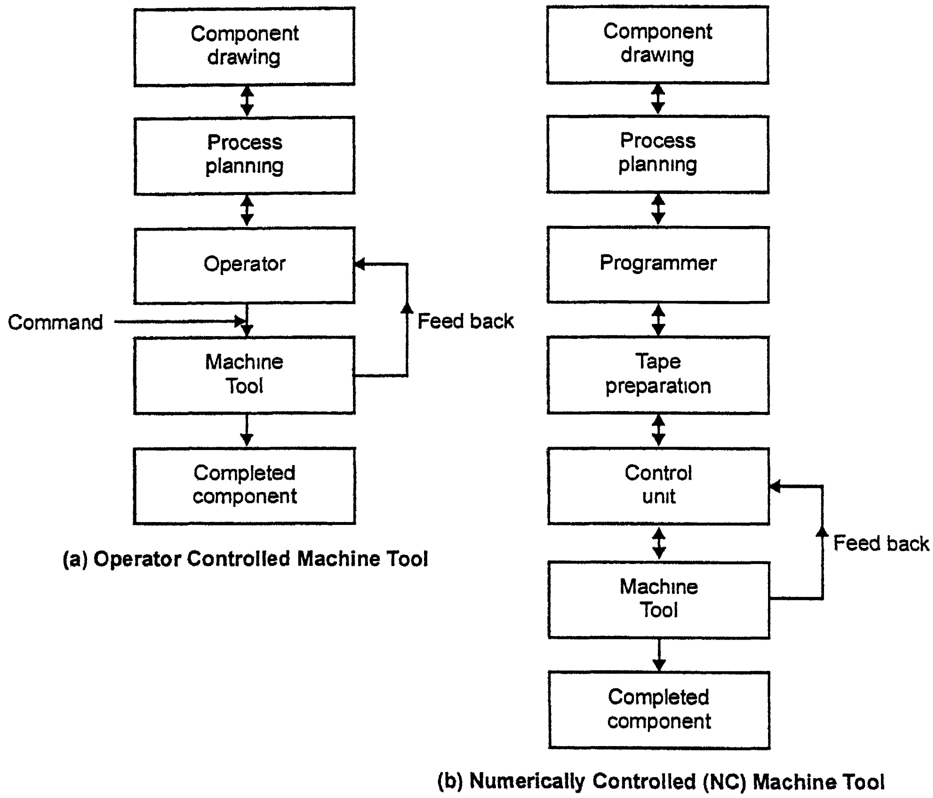


Fig. 10.59.

- In the data processing unit, the co-ordinate information regarding the component is *recorded on a tape by means of a teleprinter.*
- Tape is fed to the control unit which sends the *position command signals to slide-way transmission elements of the machine.* At the same time, the command signal is constantly *compared* with the actual position achieved, with the help of position *feedback signal derived from automatic monitoring of the machine tool slide position.* The difference in two signals, if any, is corrected until the desired component is produced.

10.10.2.3. Main Elements of a NC Machine Tool

Refer to Fig. 10.60. The main elements of a NC machine tool are :

1. The control unit (also known as NC console or Director)

2. The drive units
3. The position feedback package
4. Magnetic box
5. Manual control.

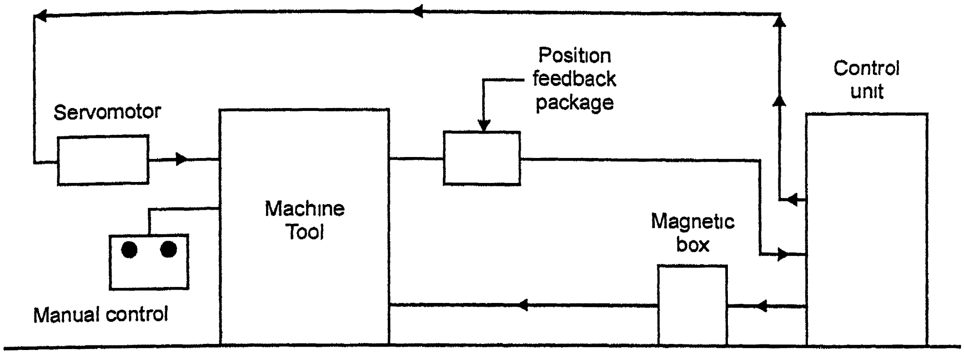


Fig. 10.60. Main elements of a NC machine.

- In the **control unit**, a tape recorder reads the instructions (written in a coded language) for manufacturing the component.
- The instructions under electronic processing and the control unit sends command signals to the **drive units** of the machine tool and also to the **Magnetic box** (Electrical control cabinet). Command signals sent to the *drive units* of the machine tool, *control the length of travel and feed rates,* while the command signals sent to the *magnetic box* control other functions such as *spindle motor starting and stopping*, selecting spindle speeds, actuation of tool change, coolant supply etc.
- A **feedback transducer** provided in the machine tool checks whether the required lengths of travel have been obtained. It sends the information of the actual position achieved to the control unit. In case there is any difference between the input command signal and the actual position achieved, the drive unit is actuated by suitable amplifier from the error signal.
- **Manual Control** provided in the machine tool assists the operator to perform some functions manually such as motor start-stop, speed change, feed change, axes movements, coolant supply etc.

10.10.2.4. Classification of NC Machines

NC machines may be *classified* as follows :

A. *According to control system :*

1. Point-to-point system .... The machining is done at specific positions.
Example : *Drilling machine* operation.
2. Straight line system .... It is an extension of point to point system.
Example : *Stepped turning on lathe, pocket milling* etc.

3. Contour system	....	There are continuous, simultaneous and co-ordinated motions of the tool and workpiece along different coordinate axes. **Example** : Machining of profiles, contour and curved surfaces.
B. *According to feedback :*		
1. Open loop system	....	There is *no 'feedback'* and no return signal to indicate whether the tool has reached the correct position at the end of operation or not. **Example :** *Co-ordinate drilling machine.*
2. Closed loop system	....	A *feedback* is built into the system, which automatically monitors the position of the tool. It is more expensive than an open loop system.

10.10.2.5. Applications of NC machines

The *major applications* of NC machines are :

1. Complex parts.
2. Parts which are frequently subjected to design changes.
3. Repetitive and precision quality parts which are to be produced in low to medium batch quantity.
4. To cut down lead time in manufacture.
5. In situations where the investment on tooling and fixture inventory will be high if parts are made on conventional machines tools.

10.10.2.6. Advantages of NC machines

Following are the *advantages* of NC machines :

1. Accuracy achieved is of high order.
2. Reduced production cost per piece.
3. Less scap.
4. High production rates.
5. Less operator skill required.
6. Excellent reliability.
7. Tooling cost low.
8. Less cycle time and increased tool life.
9. Increased flexibility.
10. Production of complex parts.
11. Reduced set-up time.
12. Elimination of special jigs and fixtures.
13. Reduced inspection.

14. Lower labour cost.
15. Reduced floor space.
16. Easy and effective production planning.

10.10.3. CNC Machines

In a CNC machine, a *minicomputer is used to control machine tool functions from stored in information or punched tape input* or *computer terminal input.*

The definition CNC (Computer Numerical Control) as given by EIA is as under :

"The numerical control system where a dedicated, stored program computer is used to perform some or all of the basic numerical control functions in accordance with control programms stored in read/write memory (RAM) of the computer".

CNC may also be defined as : *"An NC system with a microcomputer or microprocessor using software to implement control algorithms".*

Fig. 10.61 shows the control unit and panel of a CNC. The following points about CNC machines are worthnoting :

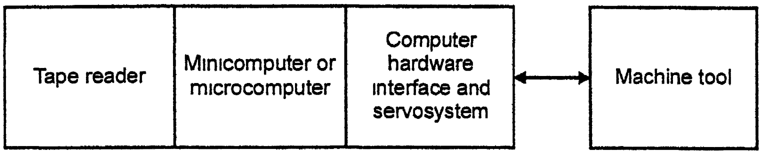


Fig. 10.61. Computer Numerical System (CNC).

- The control unit and a panel of CNC differs from that of NC controls in that, it works in *ON-line mode* whereas NC works in *batch processing mode.*
- A typical CNC may need only the drawing specifications of a part to be manufactured and the computer automatically generates the part program for the loaded part.
- The part program once entered into the computer memory can be used again and again.
- The input information can be reduced to a great extent with the use of special sub-programs developed for repetitive machining sequences.
- The CNC machines have the facility for proving the part program without actually running it on the machine tool.
- CNC control unit allows compensation for any changes in the dimensions of the cutting tool.
- With CNC control systems, it is possible to obtain information on machine utilisation which is useful to the managements.

10.10.3.1. Functions of CNC

The principal functions of CNC are :

1. Machine tool control.
2. In-process compensation.
3. Improved programming and operating features.
4. Diagnostics.

10.10.3.2. Advantages of CNC Machines (Over NC Machines)

Following are the **advantages** of CNC machines :

1. Greater flexibility.
2. Reduced data reading error.
3. CNC machine can diagnose program and can detect the machine malfunctioning even before the part is produced.
4. In highly sophisticated manufacturing systems CNC machine can be integrated with DNC (Direct Numerical Control) systems.
5. Conversion of units — possible within the computer memory.

10.10.3.3. Disadvantages of CNC Machines

1. Higher investment cost.
2. Higher maintenance cost.
3. Costlier CNC personnel.
4. Airconditioned places are required for the installation of the machines.
5. Unsuitable for long run applications.
6. Planned support facilities.

10.10.3.4. Applications of CNC

CNC is being used in the following machines/areas :

- Drilling machines
- Turning machines
- Boring machines
- Milling machines
- Grinding machines
- Pipe bending machines
- Coil winding machines
- Flame cutting machines
- Welding, wire cut EDM and several other areas.

B. CAD/CAM

10.10.4. Introduction to CAD/CAM

CAD/CAM (Computer-Aided Design/Computer-Aided Manufacture) technology was initiated in the aerospace industry but presently it is spreading at a rapid pace in all industries.

It can be *defined* most simply as the *use of computers to translate a product's specific requirements into the final physical product.*

Following points are worth noting about CAD/CAM technology :

- With *this system, a product is designed, produced and inspected in one automatic process.*
- It plays a key *role in areas* such as *design analysis, production planning, detailing, documentation, N/C part programming, tooling fabrication, assembly, jig and fixture design, quality control, and testing.*

- Whenever any deviation is noted, a programmable controller takes automatic corrective action to compensate for the deviation. Thus a *closed loop system* is formed which produces *consistent quality products, reduces wastes* and *improves productivity.*
- CAD/CAM system is *ideally* suited for *designing and manufacturing mechanical components of free form complex with three dimensional shapes.*

10.10.5. CAD

10.10.5.1. Definition

In the modern sense, CAD (Computer Aided Designs) is defined as :

"A design process using sophisticated computer graphics techniques, backed up with computer software packages to aid in the analytical, development, costing and ergonomic problems associated with design work".

10.10.5.2. Advantages

The following are the advantages of CAD :

1. Drawings can be produced at a faster rate.
2. Drawings produced by CAD systems are more accurate and neat.
3. In this system there is no repetition of the drawings.
4. CAD systems assimilate several special draughting techniques which are not available with conventional means.
5. Design calculations and analysis can be carried out quickly.
6. With CAD systems superior design forms can be produced.
7. CAD simulation and analysis techniques can drastically cut the time and money spent on prototype testing and development — often the costliest stage in the design process.
8. Using CAD systems design can be integrated with other disciplines.

10.10.6. CAM

10.10.6.1. General Aspects

CAM (Computer-Aided Manufacture) concerns any automatic manufacturing process which is controlled by computers.

The most important elements of CAM are :

1. CNC manufacturing and programming techniques.
2. Computer controlled robotics manufacture and assembly.
3. Flexible Manufacturing Systems (FMS).
4. Computer Aided Inspection (CAI) techniques.
5. Computer Aided Testing (CAT) techniques.

10.10.6.2. Advantages

CAM entails the following *advantages :*

1. Product obtained is superior in quality.
2. The manufactured form has a greater versatility.

3. Higher production rates with lower work-forces.
4. There is less likelyhood of human error.
5. As a result of increased manufacturing efficiency cost savings are materialised.
6. The production processes can be repeated via storage of data.

10.10.7. Software and Hardware for CAD/CAM

The functions of CAD/CAM system are mainly determined by the *software.*

Software usually consists of a *number of separate application packages to perform the desired function.* The size of computer depends on the number and sizes of packages and number of work stations.

Hardware is responsible for the reliability and speed of response of the system.

A wide range of standard software is available and generally it is not worth developing users own software. Though a system can be built up from standard software packages from different sources and standard hardware, it is often costly because of the considerable programming effort required to interface the packages to a common data base to provide user friendly software to adapt the system to the user's requirements. It is thus *advisable to adopt turn key system for turn key suppliers.*

10.10.8. Functioning of CAD/CAM System

- CAD/CAM is *an interactive computer graphic tool that enhances design and manufacturing functions to create a highly profitable product.* This technique is being applied by big industries for improving overall manufacturing performance.
- It is *not* a standard tool which can be fitted into any company but has to be tailored to suit the needs of the company. It is rather complex technology and has wide potential for immediate benefits.
- Usually this *tool consists of a dedicated computer, which is connected to a number of work-stations.* The system is used to assist in the design and manufacturing, through the use of an *expandable set of linked software modules.* A designer can define dimensions and display views of 2 dimensions, $2\frac{1}{2}$ dimensions and 3 dimensions parts on modules. It is possible to generate the families of part directly by a parametric processor either by direct scaling or using a catalogue of subprograms. From the geometric definition a solid model can be constructed, to assist in visualisation. It is possible to store complete details of designs on numerical control types for subsequent use on demand. Bench making tests are carried out to ensure system's capability.

10.10.9. Features and Characteristics of CAD/CAM System

The following are the features and characteristics of CAD/CAM system :

1. A major portion of the output of the engineering sector involves batch production and CAD/CAM offers immense cost and quality benefits for such requirements.
2. The work-in-progress, in batch production, is reduced considerably.

3. It is possible to produce at random all the variants and series of a product planned to be manufactured by a firm.
4. Such a system has inherent flexibility to cater to new models of the product in pipeline without major modification.
5. In such a system, several machining centres are arranged one after the other with robots and proper automatic materials handling equipment. Software is developed to integrate the machine CNC control and the handling system. Each machining centre is equipped with several tool magazines. All the tools required to complete each operation on each model of the product can be stored in the magazine.
6. All the part programs for the different models are stored in the memory. System has only to identify the model of the product presented to a machine in order to complete the machining operations. Thus it is possible to have totally random mixes of models of a product proceeding down the line at any one time.
7 The system can be conceived in multiplies of 15-20 minutes operations. If certain operations take longer, then multiples of similar machines can be installed in the line. Sometimes identical machines are introduced for each operation so that production can continue even if one machine goes down.
8. • The components are loaded on to a pallet. Means are provided to identify the exact model.
   • Loaded pallets enter the line and wait at the start of the line until a signal that one of the first operation machines is vacant is obtained.
   • The handling system automatically directs the pallet to the first vacant machine for first operation.
   • The pallets are loaded on a fixture. The fixture is designed so that it permits access to all four sides and end faces and wherever machining operation is required. The pallets are designed to have windows where access for machining is required.
   • As the pallet enters the machining area, air blast clears both the fixture and pallet locations. The fixture is then properly clamped and supported. Touch trigger probes are used to check its location in the pallet.
   • Probes also identify the exact model of the component and signals from the probes active master calling program which selects the appropriate past program and sub-routines from the control memory.
   • An overhead cascade coolant wash is provided to clear away swarf before the pallet is located. All coolant and swarf is carried away via underground ducts to a central separation and coolant filteration plant.

Some systems can show metal being removed dynamically.

- It is possible to store libraries of standard tools and tool holders, thus carrying out process planning.
- By calling up and manipulating standard fixturing components, like studs, stops, clamps, bushes, location devices, fixtures etc., it is possible to design a fixture for a component already designed on the CAD/CAM system.

- It also allows sheet metal development (unfolding), taking account of the material for the bends. It is also possible to layout sheet metal components on a standard sheet to reduce the waste (nesting). Factory layout process planning and robot programming have also been attempted.
- Exploded views, schematics and diagrams, 3-D colour shades like photographic views of the parts can be produced.
- Tenders and estimates can be quickly produced to high quality.

10.10.10. Application Areas for CAD/CAM

The potential application areas for CAD/CAM are :

1. Design and design analysis :

- CAD system would be best suited for *drawing offices where frequent modifications are required on drawing and several parts repeat.*
- It must be remembered that it is very easy with computer to make modifications and very fast to draw part profile once its details are fed into computer.
- Once a drawing is entered in the CAD system, later modifications can be done quickly, and detail drawings can be prepared quickly from a general arrangement drawing
- NC tapes can be produced.
- Storing of the drawing is very convenient, easy, occupies very less space and symbols for electrical, hydraulic, control and instrumentation circuits can be called up quickly and positioned on the schematic drawing.
- Standard components can be stored permanently in the data base and called up and positioned on the drawing, resulting in saving of time and enforcement of standards. It is possible to associate nongraphical information like past number, supplier, material etc. for any component assembly.
- It is very convenient to calculate properties like weight, centre of gravity, moment of inertia, etc. because 3-D models can be easily produced.
- It is also possible to carry out finite element analysis by producing meshing for analysis.

2. Manufacture :

- With CAD/CAM system the complete NC part programming process can be carried out interactively, including post processing and production of NC tape. Source programs in languages such as APT can be produced. Systems can verify tapes by producing tool centre path plots.

QUESTIONS WITH ANSWERS

Q. 10.1. What do you understand by tool signature ? Draw the three views of a single-point cutting tool showing all of the angles mentioned in tool signature.

Ans. The *seven important elements comprise the signature of the cutting tool and are always stated in the following order :*

(*i*) Back rake angle;

(ii) Side rake angle,
(iii) End relief angle;
(iv) Side relief angle;
(v) End cutting edge angle;
(vi) Side cutting edge angle;
(vii) Nose radius.

It is usual practice to omit the symbols for degrees and mm, simply listing the numerical value of each component. The angles are shown in Fig. 10.3.

Q. 10.2. What are the advantages of providing side cutting edge angle (lead angle or principal edge angle) on the cutting tools ?

Ans. • *Large side cutting edge angle* decreases the chip thickness, measured perpendicular to the cutting edge. Smaller chip thickness means less load on the tool and decreased wear. Or for keeping the same loading and wear conditions, *feed can be increased and thus production rate will be high.*

• Further if side cutting edge is more than 0, then the tool will first make contact at a point only which will gradually keep on increasing, thus load comes gradually on the tool. Also the first contact is at a position back of the point where the tool is quite strong. Due to gradual pick-up of load, it is specially advantageous when hard surfaces as of castings are to be machined. On the other hand, a tool with side cutting edge angle of 0 will pick-up the full load on the first contact, resulting in a shock or impact loading and reduced tool life. *Increasing side cutting edge angle too much is also not desirable as it would result in increase of radial force which can bend the work and cause chattering unless the work is stiff or well supported.*

Q. 10.3. Explain the process of chip formation in metal cutting.

Ans. The cutting tool removes the metal from the workpiece in the form of chips. *As the tool advances into the workpiece, the metal infront of the tool is compressed and when the compression limit of the metal has been exceeded, it is separated from the workpiece and flows plastically in the form of chip.* The plastic flow of the metal takes place in a localised region called *shear plane,* which extends from the cutting edge obliquely upto the uncut surface infront of the tool. The cutting tool causes shearing action bearing the metal along the plane (Fig. 10.62).

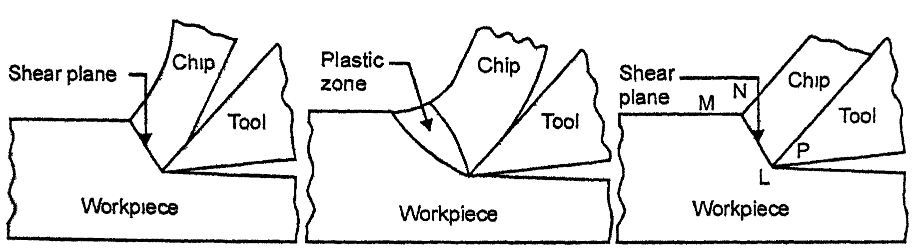


Fig. 10.62. Chip formation.

The shearing of the metal in the process of chip formation does not however, occur sharply across a straight line. The grains of the metal infront of the cutting edge of the tool start elongating along the line LM and continues to do so until they are completely deformed along the line NP. The region between the lines LM and NP is called *shear zone.* After passing out the shear zone, the deformed metal in the form of chip, slides along the tool face due to the velocity of the tool. This shear zone is treated as a shear plane for the mathematical analysis.

- Every machining operation involves the formation of chips, the nature of which depends upon the *operation, properties of the workpiece material and cutting conditions.*

Q. 10.4. Explain the process of crater formation on cutting tools. Why crater is formed at some distance above the tool tip ?

Ans. Crater formation *in metal cutting occurs due to rubbing action of continuous chip with the tool material at chip-tool interface.* The creater is formed ahead of the cutting edge because cratering effect is temperature dependent. Maximum interface temperature is mid-way of chip-tool contact length. Each mode, *i.e.,* adhesion wear, diffusion wear, abrasion wear, chemical wear is temperature dependent.

Q. 10.5. What are various primary metal cutting processes used for producing flat surfaces? What is the accuracy obtained by each process ?

Ans. The various primary metal cutting processes used for producing flat surfaces are :

1. Shaping
2. Slotting or vertical shaping
3. Planing and milling.

The accuracies obtained on these machines depend on the following factors :

(*i*) *Rigidity of the machine, shock absorbing properties of the materials used for casting of the machine and the precisions of the machines* on which the components of these machines are manufactured.

(*ii*) *Type of tool used* on the machine; single cutting tools provide less accuracies as compared to the accuracies obtainable with multipoint cutting tools.

(*iii*) *Speeds, feeds and depth of cut available on these machines.* The least count of the various motions available on the machine is a measure of accuracy obtainable on the respective machine.

Q. 10.6. Why can relief or clearance angles never be zero or negative ?

Ans. Relief (or clearance) angles are provided to prevent the end which is parallel to work, and the side, which is at the cutting edge, from rubbing on the work. If these are made zero or negative or even very small, then these will *wear down and rubbing starts. This will lead to heating up of tool, chatter marks and marking up of smeared surfaces on the work.* Thus relief or clearance angle can never be made zero or negative.

Q. 10.7. Why a built-up edge on a tool is undesirable ?

Ans. A built up edge on a tool *increases the frictional resistance* to chip flow across the face of the tool. It *results in increased heat at chip-tool interface, absorption of more power and poor surface finish on the workpiece.*

Q. 10.8. What is the effect of cutting speed, depth of cut and feed rate on the forces on cutting tool ?

Ans. Forces on the cutting tool *increases only slightly with increase in speed* though the friction is less at higher speeds. With negative rake tools and carbides, the forces actually decrease at very high speeds.

Both depth of cut and feed rate also lead to *increase in forces on cutting tool,* but forces due to *increase in feed rate are less than due to increase in depth.*

Q. 10.9. What should be done to remove maximum material per minute with the same tool life and at the same time keeping good finish ?

Ans. The best method to increase material removal rate is *to increase depth of cut, as tool life is least affected by increase in depth of cut.* If depth of cut is increased, speed needs to be decreased for same tool life. However, depth of cut is also *restricted by the strength of the workpiece and amount of stock to be removed. Increase in feed rate has smallest decrease in tool life in relation to the increased metal removal rate.* Increasing feed rate beyond finish requirements is not possible. *Thus increase in feed is best method, of course, within limits of allowable finish.*

Q. 10.10. What are the sources of heat in metal cutting ?

Ans. The main sources of heat in metal cutting on a cutting tool are :

1. The shear zone.
2. The chip tool interface continuous zone.
3. The work tool interface zone.

The above three zones are shown in Fig. 10.63.

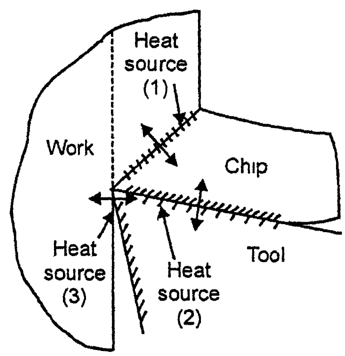


Fig. 10.63. The main sources of heat in metal cutting.

1. The shear zone. This is the zone where the plastic deformatrion is carried out due to shear energy. Due to this energy the temperature of chip rises and part of this heat is carried away by the chip when it is moving upward along the tool.

In case of continuous type chip, the cutting speed is more for a given rate of feed and chip thickness decreases and less shear energy required, accordingly less heat is generated.

2. The chip tool interface-continuous zone. It is the zone where secondary plastic deformation takes place due to friction between chip and tool. Here the temperature further rises than shear zone.

3. The work tool interface. This zone is at flanks where friction rubbing occurs.

Almost 80% of the heat generated will be transferred to the chip and 10% each in tool and work materials.

Q. 10.11. What are the factors influencing in the selection of cutting speeds and feeds for a machining operation ?

Ans. *Important factors influencing speeds and feeds for metal cutting are :*

1. Machinability of workpiece material.
2. Material of cutting tool.
3. Objective criteria, *i.e.,* whether cost or time or surface finish/tolerance are of priority.
4. Cutting fluid used.

Q. 10.12. What are the factors which influence cutting temperature ?

Ans. Following are the *factors which influence the cutting temperature.*

1. Workpiece and tool material. Tensile strength and hardness of workpiece material leave considerable influence on cutting temperature. Materials with high thermal conductivity produce lower temperatures than tools with lower conductivity.

2. Cutting conditions. The cutting speed has predominant effect on the cutting temperature. Feed has little effect and depth of cut the least.

3. Cutting fluid. At high speeds, such as employed for carbides, cutting fluid has negligible effect on tool-chip interface temperature. The fluid is carried away by the outward flowing chip more rapidly than it could be forced between the tool and the chip.

4. Tool geometry. While rake angle has only a slight influence on the temperature, it increases considerably with increase in approach angle.

Q. 10.13. Why are chip breakers used ?

Ans. A continuous type of chip from a long cut is usually quite troublesome. Such chips foul the tools, clutter up the machine and workpiece, besides being extremely difficult to remove from the swarf tray. They should be broken into comparatively small pieces for ease of handling and to prevent it from being a work hazard. Hence chip breakers are used *to reduce the swarf into small pieces as they are formed.* The fact that the metal is already work hardened helps the chip breaker to perform effectively. Various types of chip breakers are made, but all of them consist mainly of a *step or groove ground into the leading edge of the tool or a piece of cutting tool material clamped on top of the cutting tool.*

Q. 10.14. List the major factors that influence the selection of a suitable process.

Ans. Following are the major factors that influence the selection of a suitable process :

1. Cost consideration.
2. Material of workpiece.
3. Shape of workpiece.
4. Size of workpiece.
5. Degree of accuracy.
6. Surface finish requirement.
7. Number of products to be produced.

Q. 10.15. Explain why chatter and vibration are considerably reduced when a helix cutter is used instead of a plain milling cutter during milling.

Ans. A helical cutter operates more smoothly than a plain milling cutter. It is due to the fact that if the cutter teeth are made parallel to the axis, they strike the work simultaneously across the entire width. This *result in hammering action by the tool* on the work in a regular frequency and ultimately *results in chattering of the entire set-up.* This causes a poorer surface finish and shorter tool life. A cutter having helical teeth engages with work progressively and the cutting action is continuous. This eliminates chattering and smooth cutting action takes place.

HIGHLIGHTS

1. Continuous chips are produced while machining ductile materials.
2. Discontinuous chips are produced while machining more brittle materials.
3. The *cutting speed* of a cutting tool may be defined as its rate of forward travel, through the work material, or relative to the work material.
4. *Feed* may be defined as the relatively small movement per cycle of the cutting tool relative to the workpiece in a direction which is usually normal to the cutting speed direction.

5. *Machinability* may be defined as the ease with which a material can be machined.
6. *Tool life* is defined as the time interval between its two successive regrinds.
7. Machine tools are used for machining They employ cutting tools to remove excess material from the given job.
8. A lathe is one of the oldest and perhaps most important tools ever developed.
   Types of lathe. Speed lathe, engine or central lathe, bench lathe, tool room lathe, turret and capstan lathes, automatic lathes, special purpose lathes.
   Lathe operations : Facing, plain turning, step turning, taper turning, drilling, reaming, boring, undercutting or grooving, threading, knurling and forming.
9. *Drilling* is a process of making hole or enlarging hole in an object by forcing a rotating tool called *Drill. Operations performed on a drilling machine :* Reaming, boring, counterboring, countersinking, tapping, spot facing, trepanning.
10. A *shaper* is a reciprocating type of machine tool intended primarily to produce horizontal, vertical or inclined flat surfaces (upto 1000 mm long).
11. The *planing machine* (planer) is a machine tool used in the production of flat surfaces on pieces too large or too heavy to hold in a shaper.
12. The *milling machine* is a machine tool in which metal is removed by means of a revolving cutter with many teeth, each tooth having a cutting edge which removes metal from a workpiece.
13. *Numerical control.* NC can be defined simply as control by numbers.
    CNC machine tool. A machine tool having a dedicated computer to help prepare the program and control some or all of the operations of the machine tool is called computer numerical control (CNC) machine tool.

OBJECTIVE TYPE QUESTIONS

Fill in the blanks or Say 'Yes' or "No' :

1. .... is the process of cold working the metals into different shapes by using diferent types of machine tools.
2. .... is defined as the ease of removing metal while maintaining dimensions and developing a satisfactory surface finish.
3. .... processes are material removing opeations in which the desired shape, size and surface finish on the finished product are obtained by removing surplus material.
4. Turning is a finishing process.
5. Laser beam machining is an unconventional machining process.
6. Lapping is a finishing process.
7. The .... refers to only those processes where material removal is affected by the relative motion between tool made of harder material and the workpiece.
8. .... processes are those which use electrical, chemical and other means of material removal for shaping high strength materials and for producing complicated shapes.
9. Grinding and finishing processes are those where metal is removed by a large number of hard abrasive particles or grains which may be bonded as in grinding wheels, or be in loose form as in ....

10. .... angle is the angle between the face of the tool called the rake face and normal to the machining direction.
11. .... angle is the angle between the machined surface and underside of the tool called the flank face.
12. The cutting speed is the speed with which the tool moves through the work material.
13. .... may be defined as the small relative movement per cycle (per revolution or per stroke) of the cutting tool in a direction usually normal to the cutting speed direction.
14. The tool material must not remain harder than work material at elevated temperature.
15. The coefficient of friction at chip tool interface must remain .... for minimum wear and reasonable surface finish.
16. While selecting proper tool material the type of service to which the tool will be subjected should be given least consideration.
17. .... tool steels are characterised by the low stability of the supercooled austenite.
18. Stellites cannot be forged to shape.
19. The most important properties of cemented carbides are very high heat and wear resistance.
20. .... is a class of material used to sharpen the edges of cutting tools, and to reduce or polish metallic or other surfaces.
21. Carborundum is a trade name of .... carbide.
22. .... is defined as the time interval between the two successive grinds.
23. The continous chips are produced while machine less ductile materials.
24. The continuous type of chip is most desirable.
25. .... chips are usually produced while cutting more brittle materials.
26. A .... is one of the oldest and perhaps the most important machine tools ever developed.
27. Facing is an operation of machining the ends of a workpiece to produce a flat surface square with the axis.
28. A .... may be defined as a uniform increase or decrease in diameter of a piece of work measured along its length.
29. .... turning means to produce a conical surface by gradual reduction in diameter from a cylindrical workpiece.
30. .... is the operation of enlarging and turning a hole produced by drilling, punching, casting or forging.
31. The tool used in a reaming process is called ....
32. Undercutting is the process of reducing the diameter of a workpiece over a very narrow surface.
33. .... is an operation of embossing a diamond shaped pattern on the surface of a workpiece.
34. .... is an operation of turning a convex, concave or any irregular shape.
35. .... is the distance the tool advances for each revolution of the work.
36. Depth of cut is the perpendicular distance measured from the machined surface to the uncut surface of work.
37. .... is the process of making hole or enlarging a hole in an object by forcing a rotating tool called 'drill'.

38. .... is an operation in which threads are cut in the existing hole.
39 .... is an operation of enlarging a drilled hole partially. That is for a specific length.
40. A .... is a reciprocating type of machine tool intended primarily to produce horizontal, vertical or inclined flat surfaces.
41. A .... is machine tool used in production of flat surfaces on workpieces too large or too heavy to hold in a shaper.
42. The .... machine is a machine tool in which metal is removed by means of a revolving cutter with many teeth, each tooth having a cutting edge which removes metal from a workpiece.
43. .... cutting is an operation in which a pair of side milling cutters is used for machining two parallel vertical faces of a workpiece simultaneously.
44. Numerical control can be defined simply as control by ....
45. A machine tool having a dedicated computer to help prepare the program and control some or all of the operations of the machine tool is called .... machine tool.
46. In NC machines the input information for controlling the machine tool motion is provided by means of punched tapes or magnetic tapes in a coded language.
47. In NC machine tool the operator is replaced by the data processing unit of the system and .... unit.
48. The magnetic box is one of the main elements of a NC machine tool.
49. Closed loop system is less expensive than open loop system.
50. NC machines cannot be used for manufacturing complex parts.
51. The use of NC machines cuts down the lead time in manufacturing.
52. In case of NC machines, the production rates are low.
53. In a CNC machine, a .... is used to control machine tool functions from stored in information or punched tape input or computer terminal input.
54. CNC machines are unsuitable for long run applications.
55. CNC machines entail lower maintenance cost.

ANSWERS

1. Machining	2. Machinability	3. Machining
4. No	5. Yes	6. Yes
7. metal-cutting	8. Unconventional machining	9. lapping
10. Rake	11. Clearance	12. Yes
13. Feed rate	14. No	15. low
16. No	17. Carbon	18. Yes
19. Yes	20. Abrasive	21. silicon
22. Tool life	23. No	24. Yes
25. Discontinuous	26. lathe	27. Yes
28. taper	29. Taper	30. Boring
31. reamer	32. Yes	33. Knurling
34. Forming	35. Feed	36. Yes
37. Drilling	38. Tapping	39. Counterboring
40. shaper	41. planer	42. milling
43. straddle	44. number	45. CNC

46. Yes	**47.** control	**48.** Yes
49. No	**50.** No	**51.** Yes
52. No	**53** microcomputer	**54.** Yes
55. No		

THEORETICAL QUESTIONS

1. How are cutting tools clfassified ?
2. Describe briefly, with neat sketches, various types of chips.
3. Enumerate various type of tool materials.
4. Define *'cutting speed'* and *'feed'*.
5. Define machinability.
6. What is tool life ? On what factors does it depend ?
7. How is the size of a lathe specified ?
8. Enumerate common lathe operations which can be carried on a lathe.
9. Enumerate various lathe accessories.
10. What is a drill press ? Draw the block diagram of a drill press.
11. How are drilling machines specified ?
12. Give the classification of drilling machines.
13. List the various types of grinding machines.
14. How are shapers classified ?
15. Enumerate different parts of a shaper and explain them briefly.
16. How is the size of a shaper specified ?
17. Name and describe the various work holding devices in shapers.
18. Give the fundamental difference between a planar and a shaper.
19. How is the size of a planer specified ?
20. List and describe in brief the main parts of a planer.
21. Classify milling machines.
22. Classify milling cutteres.
23. Name and describe the principal parts of a milling machine.
24. Describe various milling processes with neat sketches.
25. What do you mean by *"Numerical control"* ?
26. What are the areas where *"Numerical control"* can be used ?
27. Describe briefly working of NC machine tool.
28. Explain with a neat diagram the main elements of a NC machine tool.
29. How are NC machines classified ?
30. Enumerate various applications of NC machines.
31. List the advantages of NC machines.
32. Define CNC.
33. What are the function of CNC ?
34. State the advantages of CNC machines over NC machines.
35. What are the disadvantages of CNC machines ?
36. What are the applications of CNC machines ?

11

Fundamentals of Grinding and Finishing

11.1. INTRODUCTION

- The grinding and finishing processes are used for final finish and superfinish. Out of various types of grinding, the most common one is *surface grinding* This process is accompanied by a certain amount of metal removal. This process can give a surface finish in a range of 1.25 μm to 0.25 μm.
- For many applications, grinding cannot meet the accuracy and surface finish requirements. For such applications workpieces are subjected to final operations. Two such operations are **honing** and **lapping.**

A. GRINDING

11.2. GRINDING PROCESS

- **Grinding** *is a metal cutting operation performed by means of a rotating abrasive tool, called "grinding wheel"*. Such wheels are made of fine grains of abrasive materials held together by a bonding material, called a "*bond*". Each individual and irregularly shaped grain acts as a cutting element (a single point cutting tool).
- Grinding is done on surfaces of almost all conceivable shapes and materials of all kinds. The grinding operation can be : (*i*) Rough (or non-precision) grinding and (*ii*) Precision grinding.
  (*i*) "**Rough grinding**" is a commonly used method for removing excess material from castings, forgings and weldments etc.

(*ii*) "**Precision grinding**" is the principal production method of cutting materials that are too hard to be machined by other conventional tools or for producing surfaces on parts to higher dimensional accuracy and a finer finish as compared to other manufacturing methods.

- **Grinding**, in *accordance with the type of surface to the ground,* is *classified* as :

(*i*) External cylindrical grinding.
(*ii*) Internal cylindrical grinding.
(*iii*) Surface grinding.
(*iv*) Form grinding.

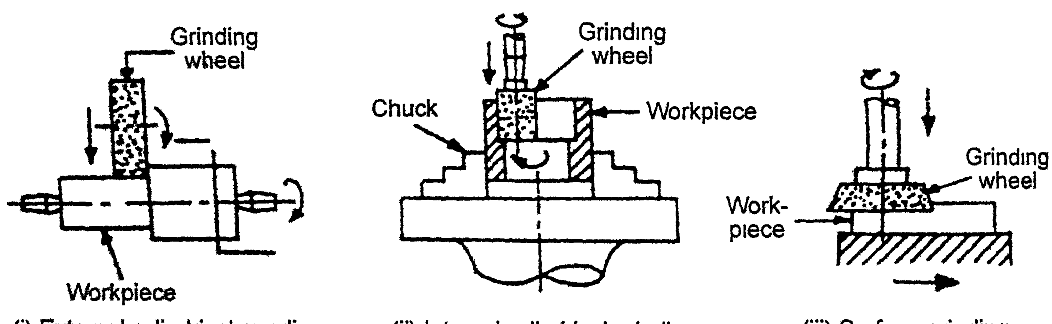
(*i*) **External cylindrical grinding.** It produces a *straight* or *tapered surface* on a workpiece. The workpiece must be rotated about its own axis between centres as it passes lengthwise across the face of a revolving grinding wheel.

(*ii*) **Internal cylindrical grinding.** It produces *internal cylindrical holes and tapers* The workpieces are chucked and precisely rotated about their own axes. The grinding wheel or, in the case of small bore holes, the cylinder wheel rotates against the sense of rotation of the workpiece.

(*iii*) **Surface grinding.** It produces *flat surface.* The work may be ground by either the periphery or by the end face of the grinding wheel. The *workpiece is reciprocated at a constant speed below or on the end face of the grinding wheel.*

(*iv*) **Form grinding.** This operation is done with *specially shaped grinding wheels* that grind the formed surface as in grinding gear teeth, threads, splined shafts, holes etc.

Fig. 11.1 shows three *basic kinds of precision grinding.*



(i) External cylindrical grinding (ii) Internal cylindrical grinding (iii) Surface grinding

Fig. 11.1. Basic kinds of precision grinding.

11.3. ADVANTAGES OF GRINDING PROCESS OVER OTHER CUTTING PROCESSES

The grinding process claims the following *advantages over other cutting processes.*

1. It is possible to achieve very accurate dimensions and smoother surface finish in a very short time.
2. It is the only method of removing material from materials after hardening.

3. Owing to large number of cutting edges on the grinding wheel it is possible to produce extremely smooth surface desirable at contact and bearing surfaces by grinding operation.
4. Complex profiles can be produced accurately with relatively inexpensive turning templates.
5. Grinding unlike conventional machining need not cut through the hard skin of forgings etc.
6. Since the grinding wheel has considerable width therefore no marks as a result of feeding are there.
7. In this process little pressure is required, thus permitting its use on very light work that would otherwise tend to spring away from the tool. This characteristic permits the use of magnetic cluck for holding the work in many grinding operations.

11.4. SPECIAL FEATUERS OF GRINDING PROCESS

Following are the *special features of grinding process* :

1. The grinding operation is intermittent in nature, and produces discontinuous chips.
2. The grinding wheel has a self sharpening character (*i.e.*, the dull or worn out grains of the grinding wheel during the operation are removed either by fracture or tearing of the bond, thus exposing fresh new grains).
3. The load acting on individual cutting grains is non-uniform.
4. The geometry of the grain is highly random and the time of contact between the chip and an abrasive grain is very small.
5. The grinding action depends strongly upon the characteristics of the grinding wheel.
6. High temperatures to the tune of 1000°C to 1400°C are usually encountered in grinding resulting into rapid grain wear and high induced surface in the workpiece.
7. The effective rake angle of abrasive grains is highly negative.
8. Grinding is associated with high specific cutting energy as compared to that encountered in conventional cutting operations.

11.5. GRINDING MACHINES

The grinding machines are *classified* as follows :

I. According to the quality of surface finish :

1. *Roughing or non-precision grinders :*
   (*i*) Bench, pedestal or floor grinders.
   (*ii*) Swing frame grinders.
   (*iii*) Portable and flexible shaft grinders.
   (*iv*) Belt grinders.
2. *Precision grinders.*

II. According to the type of the surface generated or work done :

1. *Cylindrical grinders :*
   (*i*) Plain cylindrical grinders.
   (*ii*) Universal cylindrical grinders.
   (*iii*) Centreless internal grinders.

2. *Internal grinders :*
(*i*) Plain internal grinders.
(*ii*) Universal internal grinders.
(*iii*) Chucking internal grinders.
(*iv*) Planetary internal grinders.
(*v*) Centreless internal grinders.
3. *Surface grinders :*
(*i*) *Reciprocating table :*
(*a*) Horizontal spindle (*b*) Vertical spindle.
(*ii*) *Rotating table :*
(*a*) Horizontal spindle (*b*) Vertical spindle.
4. *Tool and cutter grinders :*
(*a*) Universal (*b*) Special.
The various types of grinders are described below.

11.5.1. Plain Cylindrical Grinder

Fig. 11.2 shows a plain cylindrical grinder.

- In this type of a grinder, the workpiece is usually held between two centres One of these centres is in the *headstock* and the other in the *tailstock*.
- In operation, the rotating work is traversed across the face of the rotating grinding wheel. At the end of each traverse, the wheel is fed into the *work* by an amount equal to the depth of cut. While mounting the work between centres, the headstock centre is not disturbed. It is the tailstock centre which is moved in and out, manually or hydraulically, to insert and hold the work.

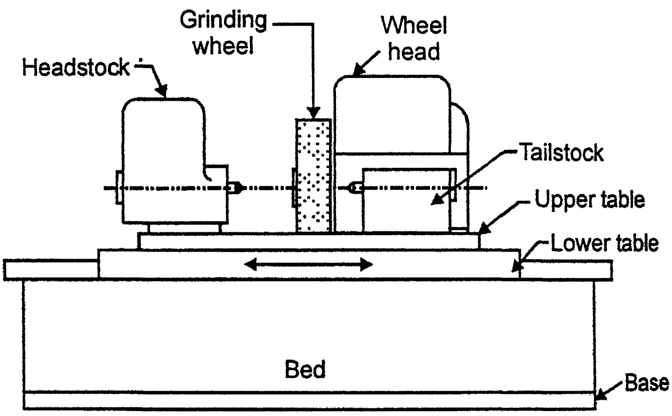


Fig. 11.2. Block diagram of a plain cylindrical grinder.

- The *table* is usally made in two parts. The upper table carries the headstock, tailstock and the workpiece and can be swelled in a horizontal plane, to a maximum of 10° on either side, along the circular ways provided on the *lower table.*
- The *wheel head* is usually mounted on the horizontal cross ways on the *bed* and travels along these to feed the wheel to the work. The movement is known as *infeed.*

'1.5.2. Centreless Grinder

Centreless grinding. Refer to Fig. 11.3.

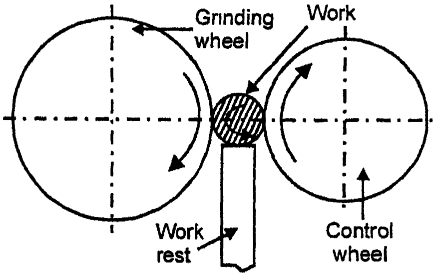


Fig. 11.3. Centreless grinding.

It is the method of grinding metallic parts in which he piece to be ground is supported on a **work-rest,** *and 'assed between a* **grinding wheel** running at a high speed nd a **controlling wheel** *running at a slow speed.* The ontrolling wheel causes the work, which must be ylinder, to revolve in the opposite direction to that of ıe grinding wheel.

The work-rest includes a number of guides that ɜed the work to the revolving wheels, and remove it as soon as the operation is over. The *ressure exerted by the grinding wheel drives the work into contact with controlling wheel and 'e work-rest.*

It will be realised from this that a point on the surface of the work where it comes into ntact with the grinding wheel revolves in the same direction as, but at a slower speed than, :orresponding point on the grinding wheel. This has the *effect of producing a more accurately 'indrical surface.*

The controlling wheel is of the same composition as the ıding wheel, and its speed can be regulated to suit the uirements. *The work revolves at the same speed as the 'trolling wheel.*

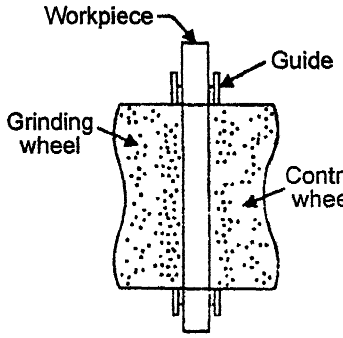


Fig. 11.4. Through feed grinding.

Following are the three standard methods of *feeding* the rk :

1. The through-feed grinding; 2. The in-feed grinding; The end-feed.

1. ***The through-feed grinding.*** Refer to Fig. 11.4.

In this type of grinding the part to be ground is *straight* d *cylindrical,* and is given an axial motion by the controlling ɑeel, passing from side to side between this and the grinding heel.

Feed rate depends on controlling wheel diameter, and peed and its angle of presentation to the work, which can e controlled.

The number of times the work passes from one side to he next depends on the thickness of material to be ground ff, and on the degree of precision required, also on the :xtent to which the part is truly cylindrical at the start of operations.

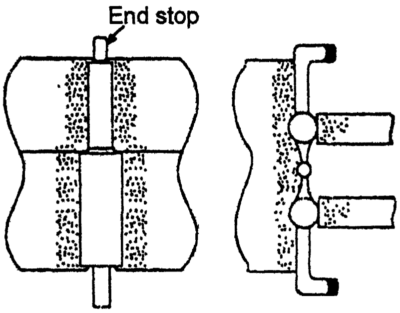


Fig. 11.5. The in-feed grinding.

2. ***The in-feed grinding.*** Refer to Fig. 11.5.

Some parts change in cross-section forming *shoulders or heads.* These are centreless ground by the *in-feed* method,

which resembles the method of form-grinding on centre grinder by taking a plunge cut. The wheel width governs the length of the portions capable of being ground in a single operation. *No axial feed is given,* but the controlling wheel is set so that its axis is roughly parallel to that of the grinding wheel. *The part is held firmly against the end stop by means of a small amount of inclination given to the controlling wheel.*

3. *The end-feel grinding.* Refer to Fig. 11.6.

While it has been said that centreless ground parts must be cylindrical, it should be noted that work having a *degree of taper* can be centreless ground by the end-feed process. In this, the grinding wheel, the controlling wheel and work rest are located in an unchanging relation to one another. The part to be ground is then automatically or by hand, fed in from the front towards a fixed end stop. Both the grinding and controlling wheels are tapered to suit the form of the work.

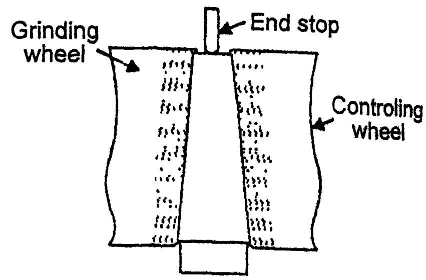


Fig. 11.6. The end-feed grinding.

Fig. 11.7 shows a centreless grinding machine and also a selection of some typical examples of components that can be ground on this type of machine (on the right).

Advantages and limitations of centreless grinding :

The following are the *advantages and limitations* of centreless grinding process :

1. There is *no need for centring* and *use of fixtures* etc.

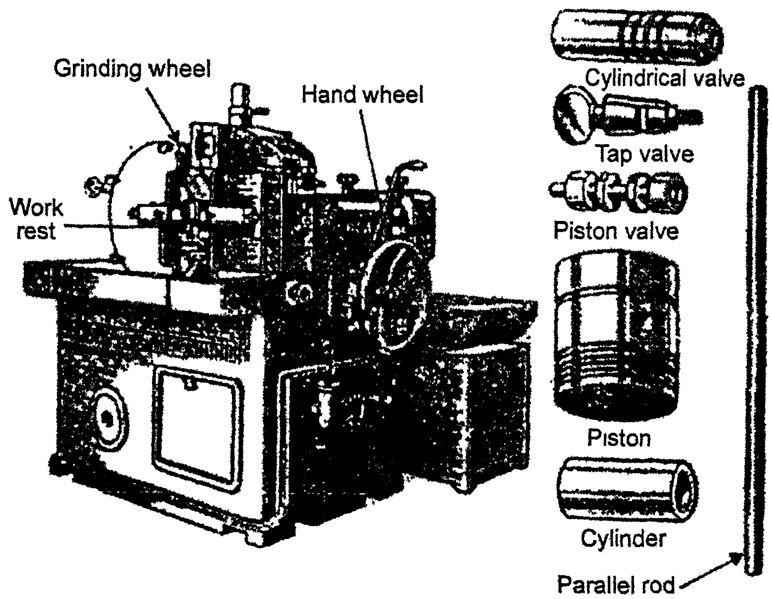


Fig. 11.7. Centreless grinding machine and example of components that can be ground on this type of machine.

2. Since during the grinding process a true floating condition exists, therefore *less metal needs to be removed.*

3. It can be applied *equally to both external and internal grinding.*
4. Since the workpiece is supported throughout the entire length as grinding takes place, therefore, *small fragile or slender workpieces may be ground easily.*
5. The process is *continuous and adapted for production work.*
6. The *size of the work is easily controlled.*
7. The requirement of wheel adjustment is *minimum.*
8. For operating centreless grinders, a *low order of skill is needed.*
9. A *very little maintenance* is needed for the machine.
10. A *large variety of components can be ground.*

Limitations :

1. The set up time for a centreless grinding operation is usually large.
2. The process is useful only for large volume production. It may be necessary to have special equipments and additional set-up time for special profiles.
3. This process is *not suitable for large workpiece sizes.*

11.5.3. Internal Grinders

Internal grinding is *the mechanical grinding of the internal bores of gears, bushes and a wide variety of machine parts.*

Fig. 11.8 shows the principle of internal grinding.

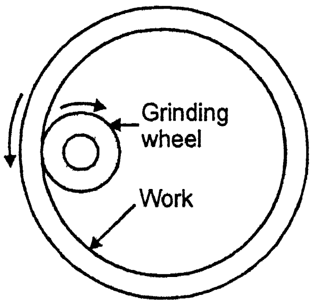


Fig. 11.8. Principle of internal grinding.

- Internal grinding is designed to complete the surfaces of holes, whether these have parallel sides, tapered bores or a combination of the two. It can also be adapted to holes of special form. It *produces accurate results,* is *not expensive* and *gives a high degree of surface finish.* It is often necessary, for instance, to remedy the slight distortion in long and slender hollow tools or parts resulting from heat treatment, and holes in these can be ground to an accuracy of 0.00635 mm, or even to 0.00254 mm. For this work choice of the right wheel is vital.

Internal grinding machines. These machines are *classified* in accordance with the *method of holding the work*, that is, *between centres or centreless;* the *traversing or non-traversing* of *the work;* and the *method of operation* whether *normal or automatic.*

In centreless grinding internally (Fig. 11.9) it is always the work that is traversed, the wheel being longitudinally fixed.

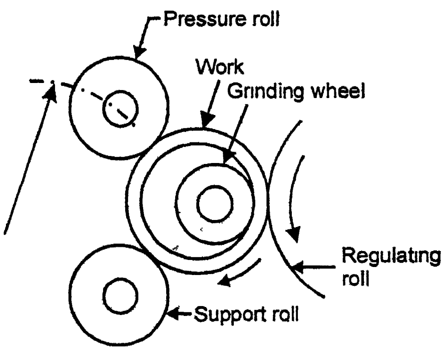


Fig. 11.9. Centreless internal grinding.

- The type of grinding wheel employed for internal grinding is *softer than that used for other types of grinding operations,* the reason being that the *area of contact between wheel and work is relatively great.*

11.5.4. Surface Grinders

Surface grinding is *the method of grinding designed to carry out the removal of metal from a part or parts less expensively and with greater precision than could be achieved by machining processes with cutting tools of steel, or by hand or machine filing.*

"Surface grinding" is particularly effective for *parts having hard spots* that would seriously blunt or impede a cutting tool, or where a hard superficial scale causes similar trouble in machining proper. The type of grinding finish resulting is often so good that a later polishing operation can be dispensed with, but for this to be so a well-designed machine is essential.

Surface-grinding machines differ according to the shape of the grinding wheel employed and the motion given to the worktable during operations. Some machines have reciprocating worktables and some have revolving worktables. They range in rigidity, size and weight from the relatively small, light machine used in the tool-room to the heavy and powerful machines which are used in the mass production of duplicate components.

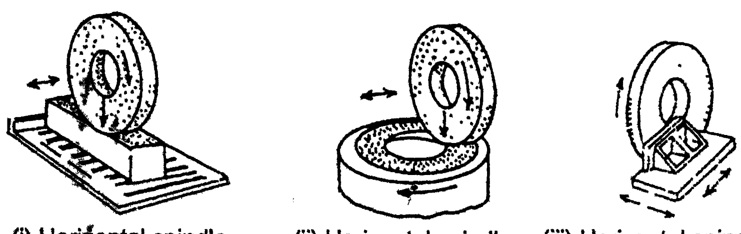
1. Horizontal-spindle surface grinding machines. These machines use the circumference of straight grinding wheels, and are able to deal with a wide range of work needing superior finish and *extremely fine limits of accuracy.* They yield a *greater output and take off metal faster than similar machines* using cup-shaped, segmental or annular wheels. If a rotating worktable is used, a finish comprising concentric circles can be obtained and is often popular.

2. Vertical-spindle flat grinding machines. These grinders remove metal faster when using a cup, cylindrical or segmental wheel than when using a straight wheel. They have a *great precision,* and if strong and rigidly built can grind to extremely fine limits.

- **Disc grinding** is a form of surface grinding. In it one disc (or more) of abrasive type is mounted on a vertical spindle so that the plane of the disc is horizontal, the work resting on the surface of a flat, rotating carrier or worktable.

Disc grinding machines are employed where rough and semi-precision grinding is desired, and where material must be ground off rapidly and effectively to tolerances somewhat greater than the most severe type. Their use in such cases is highly economical Typical examples of work done by disc grinding are the sharpening of tools, forming the square ends of disc blanks, gear and crankcase covers etc. The abrasive discs are fairly thick and are usually reinforced with steel.

Fig. 11.10 shows various types of surface grinding machines :



(i) Horizontal spindle reciprocating table (ii) Horizontal spindle rotary table (iii) Horizontal spindle single disc

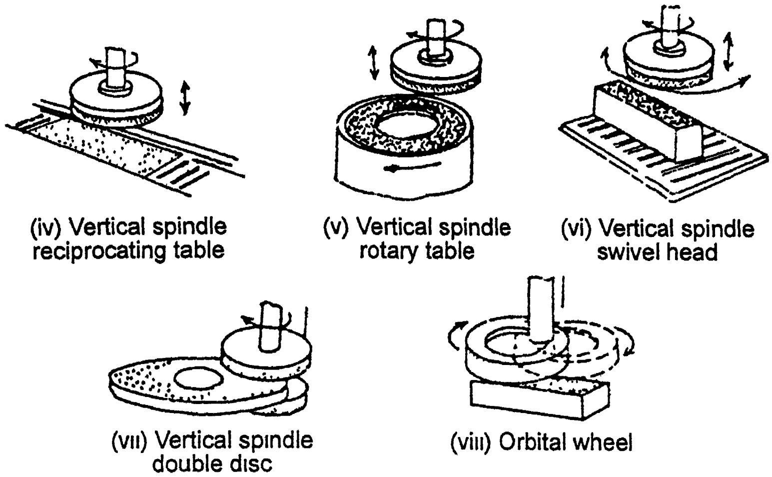


Fig. 11.10. Surface grinding machines.

11.5.5. Form Grinding

Form grinding is *grinding of tools, designed for machining and other operations, in such a way that they are provided with the precise form required for their work; or regrinding them to restore the form after it has been lost as a result of service conditions.* Form grinding must *be done with great accuracy.*

11.6. THE GRINDING WHEEL

- A **grinding wheel** *is a multi-tooth cutter made up of many hard particles known as 'abrasive' which have been crushed to leave sharp edges which do the cutting.* The abrasive grains are mixed with a suitable bond, which acts as a matrix or holder when the wheel is in use.
- The wheel may consist of one piece or of segments of abrasive blocks built up into a solid wheel.
- The abrasive wheel is usually mounted on some form of machine adapted to a particular type of work.
- The performance of a grinding wheel is usually evaluated in term of the grinding ratio (G) which is defined as :

$$G = \frac{\text{Volume of material required}}{\text{Volume of wheel wear}}$$

For fine grinding operations such as horizontal surface grinding, the value of G is usually in the range of 10 to 60, while for rough grinding operations it is much less than 10.

11.7. ABRASIVES

An *'abrasive' is a substance that is used for grinding and polishing operations.*

Abrasives may be classified as follows :

1. *Natural :*

(*i*) Sandstone (*ii*) Emery

(*iii*) Corundum (*iv*) Diamonds.

2. *Artificial :*

(*i*) Silicon carbide (*ii*) Aluminum oxide.

Natural Abrasives :

Almost all of the natural abrasives, except diamond are now considered obsolete.

- The **sandstone** is used only for sharpening wood-working tools.
- **Emery and corundum** are the materials which were widely used formerly but now these have been replaced completely by artificial abrasives.
- **Diamond** is largely used for dressing the grinding wheels and as an abrasive for grinding hard materials.

Artificial Abrasives :

1. Silicon carbide (SiC) :

- Silicon carbide abrasive is manufactured from 56 parts of silicon sand, 34 parts of powdered coke, 2 parts of salt, and 12 parts of saw dust.
- There are two types of silicon carbide abrasives :
  (*i*) *Green grit* which contains at least 97% silicon carbide.
  (*ii*) *Black grit* which contains at least 95% silicon carbide.
- It follows the diamond in order of hardness, but it is not as tough as aluminium oxide.
- It is employed for grinding materials of *low tensile strength* such as *cemented carbides, stone* and *ceramic materials, gray cast iron* etc.

2. Aluminium oxide (Al_2O_3) :

- It is manufactured by heating mineral bauxite, a hydrated aluminium oxide clay containing silica, iron oxide, titanium oxide etc., mixed with ground coke and iron shavings in an arc-type electric furnace.
- As it is tough and is not easily fractured, it is better adopted to grinding materials of high *tensile strength*, such as carbon steels, high speed steels, tough bronzes etc.

11.8. WHEEL SHAPES

Refer to Figs. 11.11 and 11.12.

- Grinding wheels are used in almost all shapes. *Most common is disc wheel.* It has a central hole for mounting and both edges or the sides of the wheels are used.
- For grinding piston rods or pins, *rod shaped wheel* is used.
- For grinding in restricted spaces like wheel teeth, etc. *tapered edges dish shape or wheel disc shape wheels* are used.
- Some grinding wheels have shapes like saucer, cylinder, flaring cup.
- Some of the grinding wheel shapes are shown in Fig. 11.11.

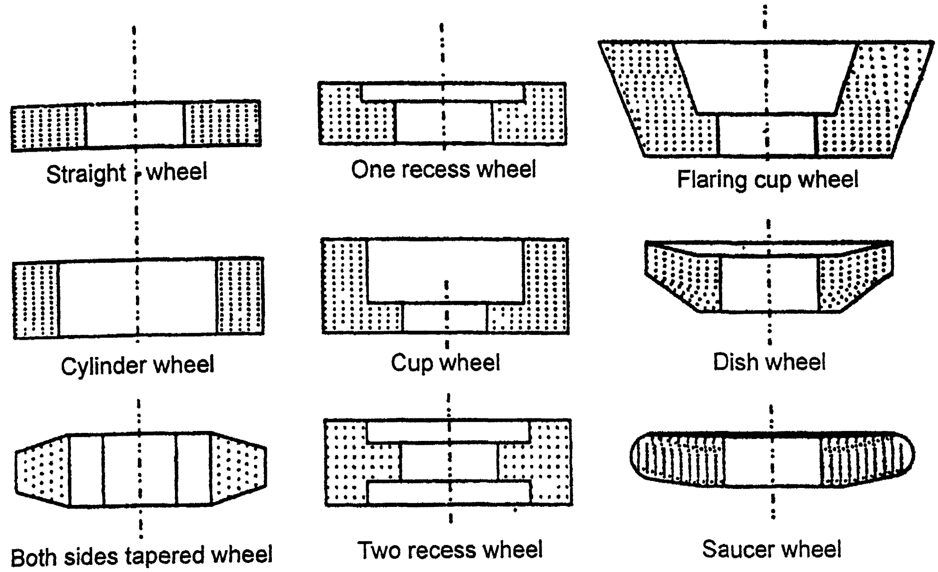


Fig. 11.11. Wheel shapes.

Maximum speeds for flexible shaft grinders :

3 × 100 mm shaft size	.... 40,000 r.p.m.
4 × 1250 mm shaft size	.... 30,000 r.p.m.
7 × 1500 mm shaft size	.... 18,000 r.p.m.
10 × 1500 mm shaft size	.... 15,000 r.p.m.
12 × 2000 mm shaft size	.... 8,000 r.p.m.
20 × 2500 mm shaft size	.... 5,000 r.p.m.

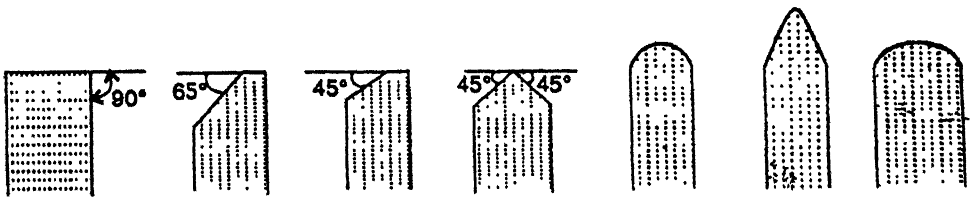


Fig. 11.12. Standard wheel edges.

Recommended wheel speeds for grinding :

	Meters/min.
Internal grinding	..... 650—1950
Surface grinding	..... 1300—1630
Knife grinding	..... 1150—1450
Cutter grinding	..... 1630—1950
Tool grinding	..... 1630—1950

11.9. MOUNTING OF WHEELS

- Normally grinding wheels are supplied with a central hole fitted with a lead bush. This is then mounted on the spindle. The wheels are clamped axially with clamping collar. To distribute the clamping pressure, soft washers are put between wheels and collars. *In absence of the soft washers, there is a danger of breaking of wheels.* The soft washers can be of the *blotting paper or any other thick paper. Small washer increases the tightening pressure or if the lead bush is out of square, the pressure of tightening may not be equalized. Large washers are therefore essential.*
- To test the soundness of wheels, these are subjected to overspeeds for testing. A good wheel should not run out of centre and should not have hollows at the testing speed. Defective wheels will crack at overspeed test.

11.10. WHEEL TRUING

In the market, two types of wheel dressers are available. 'Hunting done' type and 'Diamond dresser'. Diamond dresser can be used as a hand dresser or can be mounted. It contains a diamond point. 'Tiam carbo' dresser is substitute for 'Diamond dresser'. The wheel has to be correctly mounted and *truer can traverse wheel backwards and forwards on the saddle. The purpose of the dressing is to expose newly made sharp wheel faces for grinding. Glazed wheels do not grind and require dressing. Dressing can be carried out by pressing abrasive sticks against the wheel and then moving all along the wheel face.*

11.11. BOND MATERIALS

To ensure an effective and continuous action, it is imperative that the grains of abrasive material should be held firmly together to form a series of cutting edges. The material used for holding them is known as **bond.** The principal bonds are enumerated and described below :

1. Vitrified bond
2. Silicate bond
3. Oxychloride bond
4. Resinoid bond
5. Shellac bond
6. Rubber bond.

1. Vitrified Bond:

- It is a clay bond, reddish brown in colour.
- The base material is *Felspar* which is a fusible clay.
- The bond itself is very hard and acts as an abrasive.
- It is not affected by water, oil, acids, temperature or climatic conditions.
- The structure of the wheel is uniform due to wet mixing of different components.
- Most of the grinding wheels possess this bond.

2. Silicate Bond :

- The base material of this bond is ***silicate of soda.***
- Wheels possessing this bond are light grey in colour.
- In this case, the cutting action of the wheel is smoother and cooler.
- Extra hard wheels *cannot* be produced with this bond.

3. Oxychloride Bond :

- It is a *mixture* of ***oxide*** and ***chloride of magnesium*** and setting takes place in cold state.
- This bond provides a cool cutting action, but grinding is usually done dry.

B. FINISHING

11.12. FINISHING

For several applications, grinding cannot meet the accuracy and surface finish requirements. For such applications, workpieces are subjected to final finishing operations, *e.g.*, honing, lapping etc.

Some of the purpose of finishing surfaces of metal parts are :

(*i*) *To improve the surface appearance*— By polishing, buffing, burnishing.

(*ii*) *To improve dimensional accuracy and surface finish* (*smothness*)— By lapping, honing, superfinishing etc.

(*iii*) *To provide a clean finish* to the surfaces of a machine part, *by buffing* etc. to enable them to be coated with other metal (aluminium and mickel plating)—By electro-depositing method.

(*iv*) *To improve the functional properties of the machine parts* (*e.g.*, wear resistance, fatigue strength, power losses in friction of motion, strength of interference fits of mating parts, corrosion resistance).

11.13. HONING

Honing *is a grinding or abrading process in which very little material is removed.* It is used primarily to *remove the marks on the surface left by previous operations.*

In honing, the material is removed by abrasive sticks (aluminium oxide or silicon carbide) mounted in a mandrel or fixture. By floating action between the work and tool, the pressure exerted in the tool is transmitted equally to all sides. The honing tool is given a slow reciprocating motion as it rotates (Fig. 11.13). This action results in rapid removal of stock and at the same time the generation of a straight and and round surface.

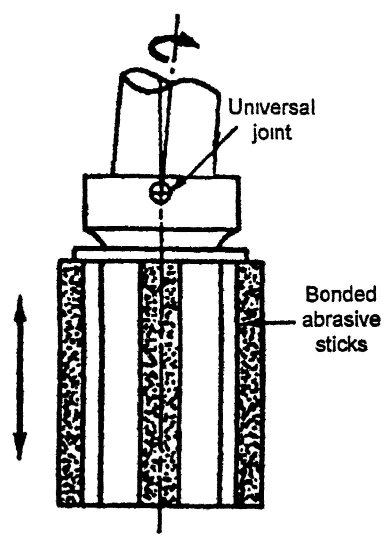


Fig. 11.13. Honing.

By honing, the surface defects, such as slight taper caused by previous operations, can be corrected.

Coolants are essentially required in this process to fluid away small chips and to keep the temperature uniform.

A metal frame which holds the abrasive sticks during honing operation is known as a ***hone*** or a ***honing tool.*** Hones are of two type :

(*i*) Internal hones. (*ii*) External hones.

Examples of honing work :

Following are the *examples of honing work :*

- Diesel engine cylinder bore.
- Roller bearing races.
- Bores of cannons.
- Automobile, aeroplane engine cylinder head bores.
- Bores in rocker arms.
- Hub holes in gears of gear boxes.

Advantages and disadvantages of honing :

Following are the *advantages* and *disadvantages* of honing :

Advantages :

1. Correction of geometrical accuracy :
   (*i*) Out of roundness
   (*ii*) Taper
   (*iii*) Axial distortions.
2. Dimensional accuracy.
3. Relatively high productivity as compared to lapping.
4. Holes of any diameter or length may be honed.
5. Several holes may be honed simultaneously on multiple spindle machines.

Disadvantages :

Tough non-ferrous metals cause glazing or clogging of the voides of the abrasive sticks and thus, they are difficult to hone.

Honing conditions :

- All materials can be honed. However, the material removal rate is affected by the hardness of the work material. The typical rates are :
  (*i*) *Soft material* — 1.15 mm/min on diameter;
  (*ii*) *Hard material* — 0.30 mm/min on diameter.
- The maximum bore size that can be conveniently honed is about 1500 mm while the minimum size is 1.5 mm in diameter.
- The honing allowance should be small to be economical. However, the amount also depends upon the previous error to be corrected.
- The abrasive and grain size to be selected depend upon the work material and the resultant finish desired.

Vertical honing machines :

- These machines hold the work and honing tool with their axes in vertical position. These machines are available in both single spindle and multiple spindle types.
- These machines are *best suited for shorter jobs.* Part lengths up to 2000 mm are usually honed in vertical honing machines.

Horizontal honing machines :

- These machines hold the work and honing tool with their axes in horizontal position. These machines are available both in single spindle and multi-spindle types.

- These machines are employed for longer jobs. Jobs more than 2000 mm are usually honed in horizontal honing machines.

Note : According to new envelopment in the field of honing, parts like cylinder blocks and liners, refrigerator compressors, gears and connecting rods are processed by *"diamond honing"*.

11.14. LAPPING

Lapping *is a finishing process following after grinding, and designed to produce an exceptionally high degree of surface finish as well as a perfectly true surface accurate to size within extremely close limits.* In some work the finish is more important than the dimensional accuracy.

In **lapping process** (Fig. 11.14) a layer of fine abrasive particles, usually suspended in a liquid, is held between the workpiece and the lap. The lap material being softer than the workpiece (generally cloth, copper or cast iron) causes the abrasive grains to get embedded on to the lap surface when pressure is applied between the lap and the workpiece. These grains cut the work in the same way as in grinding when relative motion is provided between the workpiece and the lap. Because of variations in grain size from particle to particle, not all the grains get embedded into the lap and *these loose grains roll and slide between the workpiece and the lap and cause some material removal.* Embedded grains are however, responsible for bulk of material removed and abraded workpiece conforms to the shape of the lap.

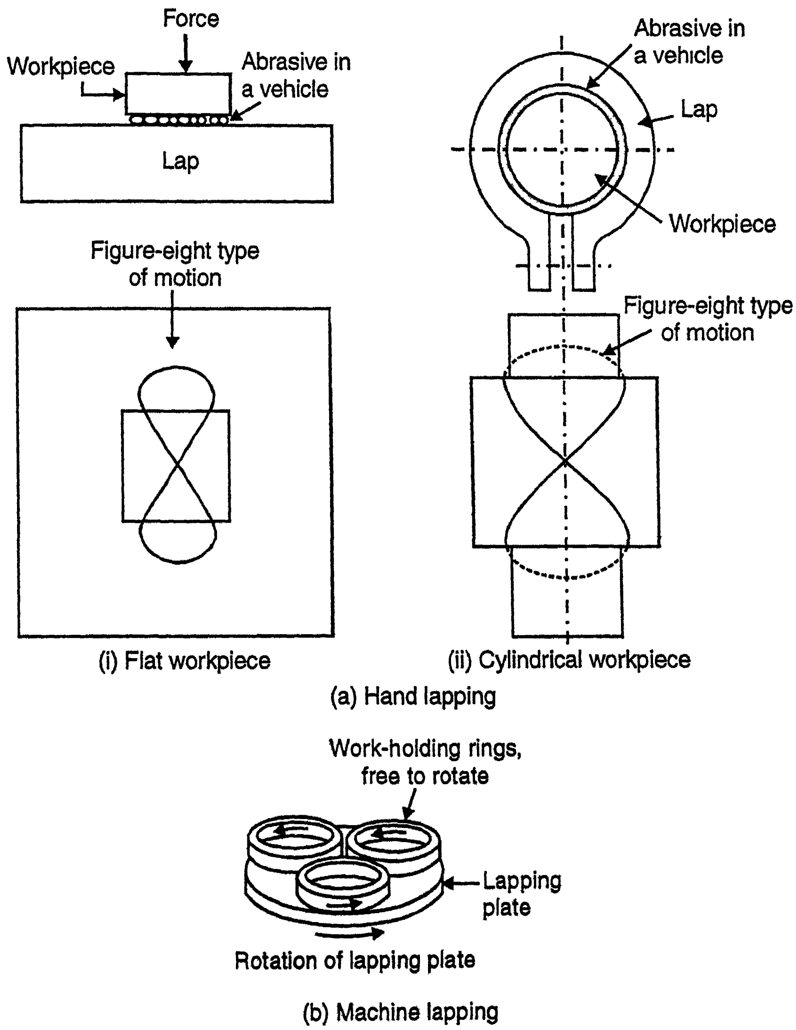


Fig. 11.14. Lapping process.

Lapping is done manually or by specially designed machines (*see* Fig 11.14). *Soft materials are lapped with* Al_2O_3 *and hard materials* with diamond or SiC grit.

- The lap materials generally used are :
  - — Cast iron;
  - — Soft steel;
  - — Bronze;
  - — Brass.

Types of lapping operations :

1. *Equalizing lapping* — When work and lap mutually improve their shape and surface, for example; when gears are run together with some abrasive, or tapered valves are seated in seats.
2. *Form lapping* — Shape of lap is imparted to the work.

Lapping Machines :

Lapping machines may be *classified* as follows :

1. General purpose lapping machines :

(*i*) Vertical axis lapping machine with metallic laps.
(*ii*) Vertical axis lapping machine with bonded abrasive wheels as laps.
(*iii*) Centreless lapping machine.
(*iv*) Abrasive belt lapping machine.

2. Single purpose lapping machines :

(*i*) Valve seat lapping machine.
(*ii*) Crankpins and journal lapping machine.
(*iii*) Crankshaft lapping machine.
(*iv*) Gear lapping machine etc.

Examples of lapping work :

1. *Hand lapping :*

- Surface plates
- Holes and pins
- Tappet valve and valve seat
- Jigs and fixture bushes
- Slip gauges
- Plug gauges etc.

2. *Machine lapping :*

- Diesel engine injectors
- Oil burner parts
- Gauges
- Ball and roller bearing faces
- Machine bearings
- Measuring instruments etc.

Advantages and Disadvantages of lapping :

Advantages:

(*i*) It can lap any type of material of any shape, if it is flat.
(*ii*) As the parts are not clamped and no heat is generated, there is no warping.
(*iii*) It produces no burrs, rather removes those left in earlier process.

Disadvantages :

The lapping is still an art because of large variables involved and thus past experience and

skill in a new job go a long way. It is important to remember that flatness, surface finish and polished surface are not obtained all at the same time and in equal quantities.

11.15. SUPERFINISHING

Superfinishing is *an abrading process, efficient in surface refining of cylindrical, flat, spherical and cone shaped parts.*

It is not primarily a dimension changing process but *mainly used for producing finished surface of fine quality on metals.* Only a slight amount of stock is removed (average 0.002 to 0.02 mm on a disc). The smoother finishes do not have scratch to exhibit any directional effect.

The honing process involves two motions whereas superfinishing requires three to five or even more. As a result of these motions the abrasive particle path is random and never repeats itself.

The operation is mainly concerned with *external work. Superfinishing is generally used for :*

(*i*) Correcting inequalities in geometry.

(*ii*) Removing surface fragmentation.

(*iii*) Reducing surface stresses and burns and thus restoring surface integrity.

Superfinishing produces a high wear resistant surface on any object which is symmetrical.

Fig. 11.15. shows the superfinishing operation.

— The contact surface in superfinishing is large and the tool maintains a rotary contact with the workpiece while oscillating as shown in Fig. 11.15.

— The typical stroke of the superfinishing stone is about 1 to 5 mm with an oscillating frequency of 2 kHz. Superfinishing speeds used are 10 to 40 m/min while the working pressure maintained is about 0.1 to 0.3 MPa. The heat generated under these conditions is appreciably small and hence *there is no metallurgical alteration of the work.*

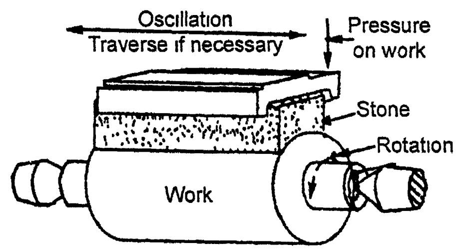


Fig. 11.15. Superfinishing operation.

— The *finish obtained on the surface depends upon the time for which the stone is in contact with the work.*

- The superfinishing operation basically differs from other abrasive finishing methods in the following *respects* :

  (*i*) It is primarily a finishing operation and not a dimensioning operation.

  (*ii*) The motion is multiple and random and very rapid.

  (*iii*) Strokes are 1 to 5 mm at 300 to 3000 reversals per minute as compared to 50 to 100 reversals of a grinding wheel.

  (*iv*) The reversal of stoke is short, as compared to the long stroke of the hone, which accumulates large amounts of chips that may scratch the surface.

(*v*) A surface finish of 0.01 micron may take 30 seconds.
(*vi*) The abrasive pressure for external surfaces is 0.2 to 0.33 kg/cm^2 against 13500 kg/cm^2 for grinding with line contact.
(*vii*) The abrasive pressure for internal surfaces is 0.2 to 2 kg/cm^2 against 35 to 70 kg/cm^2 for average honing operations.

Examples of work :

- Crankshaft journals
- Automotive pistons
- Cylindrical shanks of valve tappets
- Roller bearing surfaces etc.
- Gun recoil machining
- Automobile valve systems

11.16. COMPARISON AMONG LAPPING, HONING AND SUPERFINISHING

S.No.	*Aspects*	*Lapping*	*Honing*	*Superfinishing*
1.	*Type of process*	Abrading	Abrading	Abrading
2.	*Type of surface produced*	Used to produce geo-metrically true surface in addition to surface finish.	Used for finishing internal round holes.	Used to produce extre-mely light quality surface finish and not dimen-sional.
3.	*Abrasive tools used*	Lapping consists of the use of loose abrasive parti-cles with some vehicle. Mesh size of abrasive particles ranges from 120-1200.	It makes use of bonded sticks called *hones.* Mesh size of abrasive particles ranges from 80-600.	It also makes use of bon-ded abrasive stones, but of finer mesh size ran-ging from 400-600.
4.	*Types of surface/ material for which used*	It is normally used for hard surfaces, *e g.*, steel and cast irons.	It can be used for both soft and hard materials.	It can also be used for both soft and hard materials.
5.	*Type of process/ operation*	Finishing (metal removal is very small up to 0.025 mm)	Metal removal (metal removal is high up to 0.75 mm)	Superfishing (Metal re-moval is very small up to 0.005 mm)
6.	*Motion of the workpiece and tool*	Both workpiece and laps are in motion.	Hone is rotating whereas the workpiece is held stationary.	Both workpiece and abra-sive stone are in motion.
7.	*Pressure range*	0.7 to 30 kg/m^2	7 to 30 kg/m^2	0.21 to 319 kg/m^2

11.17. POLISHING AND BUFFING

Both these processes are *used for making the surfaces smoother along with a glossy finish.*

Polishing and buffing wheels are made of *cloth, felt or such material which is soft and has a cushioning effect.*

Polishing. It is done with a very fine abrasive in *loose form* smeared on the polishing wheel with the work rubbing against the flexible wheel. *A very small amount of material is removed in polishing.*

Examples of work : The parts to be electroplated are usually polished before plating. All those which are to have a lustrous smooth appearance without plating such as stainless steel utensils, surgical instruments, bright finished hand tools like wrenches etc. are given a final finish by polishing alone or polishing followed by buffing.

Buffing. In this process the *abrasive grains in a suitable carrying medium such as grease are applied at suitable interval to the buffing wheel.* Negligible amount of material is removed in buffing while a very high lustre is generated on the buffed surface.

Examples of work. All parts to be electroplated and made of steel and harder materials are first finished by grinding, polishing and then buffing. Then they are plated. Die cast parts are mostly first polished and then buffed before being electroplated. Sheet aluminium, brass and copper usually require only the buffing operation before electrolating.

- The *dimensional accuracy of the parts is not affected by polishing and buffing operations.*

11.18. BURNISHING

Burnishing *is an operation by which a bright, polished finish is produced on the surface of a metal by a rubbing action which smooths out small scratch marks.*

The finish is produced by the action of *burnishers,* which must be made of very hand material having a highly polished surface. When rubbed with pressure over the metal being treated, no metal is actually removed by the burnisher, but an action somewhat resembling a flow of metal takes place.

Uses :

- Burnishing is generally *used only to produce a decorative finish.*
  - Gold leaf and brass can be burnished by rubbing an agate burnisher over the surface.
  - Steel and brass can be burnished by rubbing with a number of interconnected hard steel rings mounted on a piece of leather and resembling a piece of "coat of mail".
- In some cases burnishing is used to produce a *finish which will give better wearing qualities than those left by a cutting tool. Thus, journals of railway axle* are sometimes burnished by the pressure of a plain hardened-steel roller mounted on a small shaft in the end of a tool held in a lathe slide-rest. The roller is slowly traversed along the rotating journal of the axle which is mounted on the lathe.

11.19. COMPARISON OF GRINDING AND FINISHING OPERATIONS

The comparison of grinding and finishing operations is given in the table 11.1 below.

TABLE 11.1

Comparison of Grinding and Finishing Operations

S. No.	*Process*	*Advantages*	*Limitations*
1.	*Horizontal surface grinding*	(*i*) Close tolerance (± 0.0025 mm) and good surface finish (0.2 – 2.5 μm).	(*i*) Suitable for improving tolerance and surface finish on machined surfaces.

		(ii) Suitable for grinding of flat surfaces. (iii) Medium labour skill.	(ii) Low production rate. (iii) Thermal damage may occur due to high temperature during grinding.
2.	*Vertical surface grinding*	(i) High production rate. (ii) Suitable for rough grinding of flat surfaces (iii) Medium labour skill.	(i) Suitable for stock removal only. (ii) Close tolerance cannot be obtained.
3.	*Cylindrical grinding*	(i) Tolerance and surface finish same as for horizontal surface grinding (ii) Suilable for round shapes, stepped diameters, etc. (iii) Medium labour skill.	(i) Suitable for improving tolerance and surface finish on machined surfaces. (ii) Low production rate. (iii) Thermal damage may occur due to high temperature during grinding.
4.	*Internal grinding*	(i) Tolerance and surface finish same as for horizontal surface grinding. (ii) Suitable for bores. (iii) Medium labour skill.	(i) Suitable for improving tolerance and surface finish on machined surfaces. (ii) Low production rate. (iii) Thermal damage may occur due to high temperature during grinding.
5.	*Centreless grinding*	(i) High production rate. (ii) Suitable for long, round workpieces. (iii) Low labour skill	(i) Not suitable for large diameter workpieces. (ii) Tolerances and surface finish not as good as those obtained in cylindrical grinding.
6.	*Honing*	(i) Very close tolerace ($\pm$ 0.0015 mm) and extremely good surface finish (0.01 – 0.35 μm). (ii) Suitable for bores and holes. (iii) Low labour skill. (iv) No heat distortion.	(i) Expensive operation. (ii) Very low production rate. (iii) Limited amount of material can be removed.
7.	*Lapping*	(i) Tolerance and surface finish same as that for honing. (ii) Suitable for flat surfaces. (iii) High production rate. (iv) Low labour skill. (v) No heat distortion.	(i) Limited amount of material can be removed. (ii) Expensive operation.

QUESTIONS WITH ANSWERS

Q. 11.1. What is a grinding wheel and why better surface finish is obtained when this is used as a tool? Explain.

Ans. A *"grinding wheel" is a multi-tooth cutter made up of many hard particles called*

as abrasive which is crushed to leave sharp edges, these edges perform the cutting. The abrasive grains are mixed with a suitable bond. This bond acts as a matrix or holder when the wheel is in use. The wheel may consist of one piece or of segment of abrasive blocks built up into a solid wheel.

By **bond** *we mean here an adhesive substance that is employed to hold abrasive grains together in the form of sharpening stones or grinding wheels.*

Q. 11.2. Give general guidelines for selection of bond for the grinding of a range of materials.

Ans. Selection of bond mainly depends upon the following *factors* :

1. **Constant factors** :
   - (*i*) Work metal — It should be noted that for grinding a soft material, hard wheel should be used and vice versa.
   - (*ii*) Amount and rate of stock removal.
   - (*iii*) Area of contact between work and wheel.
   - (*iv*) Condition of grinding machine — A softer grade of wheel is used on robust and heavy machine.
   - (*v*) Finish and accuracy required on the job.
2. **Variable factors** :
   - (*i*) Wheel speed.
   - (*ii*) Work speed.
   - (*iii*) Condition of grinding machine (state of wheel spindle bearing).
   - (*iv*) Skill of operator (Personal factors).

Q. 11.3. Explain briefly a surface grinder.

Ans. A surface grinder uses a cylindrical grinding wheel or cup shaped wheel to *produce a flat surface*. Segmented abrasive stones fitted on the face of a cylindrical tool are also used for surface grinding. Two classes of surface grinding are called *peripheral grinding* and *face grinding*. The various arrangements showing relative arrangements of spindle and table are shown in Fig. 11.10.

Q. 11.4. What is surface grinding? When do you recommend the use of this process ?

Ans. *'Surface grinding' produces flat or plane surfaces.* The work may be grounded by either the periphery or by the end face of the grinding wheel. The workpiece is reciprocated at a constant speed below or on the end face of the grinding wheel.

Surface grinding is done by two machines : (*i*) Planer type with a reciprocating table for work ; (*ii*) Machines with rotating table for continuous rapid grinding.

Modern surface grinding machine is provided with hydraulic control of table movements and wheel cross feed. Machine of this type is *adapted to reconditioning dies, grinding tool ways, and other long surfaces.*

Q. 11.5. Give five applications of grinding process.

Ans. Following are the *five* applications of grinding process :

1. To sharpen the cutting tools.
2. To obtain better finish on the surface.

3. To grind threads in order to have close tolerances and better finish.
4. To remove a very small amount of metal from the workpiece to bring its dimensions within very close tolerances.
5. To machine hard surfaces which are otherwise difficult to be machined by the high speed steel tools or carbide cutters.

Q. 11.6. List the factors on which the performance of grinding wheel depends.

Ans. The performance of a grinding wheel depends upon the following *factors* :

1. *Type of abrasive* — SiC is more hard and brittle, so it is chosen for C.I., brass, hard alloy etc. Al_2O_3 is more suitable for grinding of steels and bronzes.
2. *The grade of the wheel* — The grade designates the force holding the grains. The grade is also called the hardness of the wheel. The grade of a wheel depends on the kind of bond, structure of wheel and amount of abrasive grains. It is designated by a letter, with 'A' representing the soft end and 'Z' the hard end of the scale.
3. *Wheel structure* — Structure relates to the spacing of abrasive grains. Open structures are used for high stock removal and consequently produce a rough finish. Dense structures are used for precision forms and profile grinding.
4. *Grain size.*
5. *The properties of the grains.*
6. *The geometry of the cutting edges of grains* (rake angles and cutting edge radius compared to depth of cut).
7. The process parameters (speeds, feeds, cutting fluids) and type of grinding (cylindrical, surface).

Q. 11.7. What is a lap? Explain.

Ans. A **lap** *is a soft material disc, ring, ptate or cylinder, charged with abrasive powder or compound, and used for producing extremely accurate and finished surfaces.*

A lap is a cutting tool that is made by "charging" a metal body of lead, copper, soft cast iron or any other suitable soft material *with a fine abrasive*. Charging here means that the abrasive powder is embedded in the lap by rubbing or rolling :

- In general, copper and soft steel laps cut faster than cast iron laps but *cast iron laps retain their form better. Cast iron laps are widely used.* The faces of the cast iron laps are serrated, this makes it easier to remove the work after lapping and provides a storage space for oil and abrasives.
- A '*hand lap*' for finishing flat surfaces is *in the form* of a *flat plate*. The '*lapping machine*' usually *utilizes curcular disc like laps.*

Q. 11.8. What is tumbling ? Explain.

Ans. Tumbling (or liquid honing) is *the process of revolving small workpiece in a barrel with abrasive and water for the purpose of producing a high lustre or removing burrs.*

The following are the *purposes of tumbling :*

- To debur the parts.
- To produce a high finish.
- To improve micro finish.

- To finish gears or threaded parts without damage.
- To remove paint or plating from parts, or descale the parts.
- To form uniform radii around the workpieces, *i.e.*, generating controlled radii.
- To finish high precision work to a high lustre.

Q. 11.9. What is diamond machining? Explain.

Ans. Diamond is the hardest cutting tool material. It has *low friction, high thermal conductivity and low coefficient of expansion.* It finds applications for special jobs like *turning outside surface of aluminium alloy pistons, boring of while metal bearing liner to produce highly polished surface finish obtainable by superfinishing*; for *truing or forming* the *faces of grinding wheels.*

Diamonds being small are used in the form of tips which are clamped into a tool shank and the shank is mounted in tool holder, such as micro-boring head. The diamond tips are available with cutting edge either radiused or in the form of a series of flats around 0.4 mm long These edges are set accurately parallel to the work axis using a setting microscope. When the working cutting edge gets worn out (it cannot be sharpened), the other cutting edge is fixed for the cutting action. Alongwith high hardness, diamond tips are highly brittle also These must, therefore, be supported rigidly in the minimum overhange and subjected to least vibrations during cutting operation.

Q. 11.10. What for lapping is used? How much stock is left for lapping? How does it differ from grinding ?

Ans.
- Lapping process is *used to obtain truly flat and smooth surfaces.* It is *also used to finish flat and round work* to tolerance of 0.01 to 0.001 mm.
- Usually about *0.001 to 0.01 mm stock in left for lapping process.*
- Lapping differs from grinding/honing process in the respect that it *uses loose abrasive instead of bonded abrasive.*

Q. 11.11. Why is it undesirable to continue running coolant on to a grinding wheel after the wheel has stopped ?

Ans. If coolant is run continously on a grinding wheel after it has stopped, then a part of the wheel would become saturated, thereby increasing the weight of that portion and *resulting in unbalance of wheel, increasing the danger of wheel disintegration.* Further, an unbalanced wheel is *deterimental to the quality of the surface finish produced on the workpiece.*

HIGHLIGHTS

1. *Grinding* is a metal cutting operation performed by means of a rotating abrasive tool, called "grinding wheel". Grinding may be *classified* as :
   (*i*) External cylindrical grinding; (*ii*) Internal cylindrical granding; (*iii*) Surface grinding; (*iv*) Form grinding.
2. *Centreless grinding* is the method of grinding metallic parts in which the piece to be ground is supported on a work rest, and passed between a grinding wheel running at a high speed and a controlling wheel running at a slow speed.

3. *Internal grinding* is the mechanical grinding of the internal bores of gears, bushes and a wide variety of machine parts.
4. *Surface grinding* is the method of grinding designed to carry out the removal of metal from a part or parts less expensively and with greater recision than could be achieved by machining processes with cutting tools of steel, or by hand or machine filing.
5. *Form grinding* is grinding of tools, designed for machining and other machines, in such a way that they are provided with the precise form required for their work; or regrinding them to restore the form after it has been lost as a result of service conditions.
6. The *grinding wheel* is a multi-tooth cutter made up of many hard particles known as '*abrasive*' which has been crushed to leave sharp edges which do the cutting.
7. *Honing* is a grinding or abrading process in which very little material is removed. It is used primarily to remove the marks on the surface left by previous operations.
8. *Lapping* is a finishing process, following after grinding, and designed to produce an exceptioually high degree of surface finish as well as perfectly true surface accurate to size within extremely close limits.
9. *Superfinishing* is an abrading process, efficient is surface refining of cylindrical, flat, spherical and cone shaped parts.
10. *Burnishing* is an operation by which a bright, polished finish is produced on the surface of a metal by a rubbing action which smooths out small scratch marks.

OBJECTIVE TYPE QUESTIONS

Fill in the blanks or say 'Yes' or 'No' :

1. .... is a process carried out with a grinding wheel made up of abrasive grains for removing very fine quantities of material from the workpiece surface.
2. The grinding and finishing processes are used for final finish and superfinish.
3. .... grinding is a commonly used method for removing excess material from castings, forgings and weldments etc.
4. Grinding is done on surfaces of limited shapes and materials of limited kinds.
5. .... grinding is the principal production method of cutting materials that are too hard to be machined by other conventional tools or for producing surfaces on parts to higher dimensional accuracy and finer finish as compared to other manufacturing methods.
6. External cylindrical grinding produces a straight or tapered surface on a workpiece.
7. .... cylindrical grinding produces internal cylindrical holes and tapers.
8. .... grinding produces flat surface.
9. .... grinding operation is done with specially shaped grinding wheels that grind the formed surfaces as in grinding gear teeth, threads, splined shafts, holes etc.

10. In a grinding process it is possible to achieve very accurate dimensions and smoother surface finish in a very short time.
11. .... is the only method of removing material from materials after hardening.
12. The grinding operation is intermittent in nature, and produces discontinuous chips.
13. The grinding wheel has .... character.
14. In a grinding wheel the load acting on individual cutting grains is uniform.
15. The effective rare angle of abrasive grains is highly positive.
16. The geometry of the grain is highly random and the time of contact between the chip and an abrasive grain is very small.
17. The .... size indicates the sieve number used for screening grains.
18. A higher sieve number would indicate coarser grains.
19. The grade or hardness of the wheel is designated by a letter with 'A' representing the soft end and 'Z' the hard end of the scale.
20. The .... of a wheel characterizes the mean void size and the distribution of the grains.
21. Centreless grinding operations can provide surface finish in the range of 0.1 to 1.5 μm and the tolerance achievable is 0.005 to 0.03 mm.
22. When the grinding wheels lose their geometry, the original shape is restored by .... with a diamond tool.
23. The performance of a grinding wheel is usually evaluated in terms of the .... ratio.
24. The grinding ratio is defined as volume of wheel wear and volume of material removed.
25. In .... grinding process there is no need for centring and use of fixtures etc.
26. The centreless grinding process is suitable for .... volume production.
27. The centreless grinding process is not suitable for large workpiece sizes.
28. Internal grinding produces accurate results, is not expensive and gives a high degree of surface finish.
29. Disc grinding is a form of .... grinding.
30. Form grinding must be done with great accuracy.
31. A .... is a substance that is used for grinding and polishing operations.
32. Silicon carbide is employed for grinding materials of .... tensile strength.
33. Aluminium oxide is better adopted to grind materials of .... tensile strength.
34. For grinding piston rods or pins, rod shaped wheel is used.
35. .... wheels do not grind and require dressing.
36. Most of the grinding wheels possess uitrified bond.
37. Extra hard wheels can be produced with silicate bond.
38. Oxychloride bond provides a cool cutting action, but grinding is usually done dry.
39. .... is a grinding or abrading process in which little material is removed.

40. .... is primarily used to remove the marks on the surface left by previous operations.
41. A metal frame which holds the abrasive sticks during honing operation is known as a ....
42. .... is a finishing process, following after grinding, and designed to produce an exceptionally high degree of surface finish as well as perfectly true surface accurate to size within extremely close limits.
43. Soft materials are lapped with Al_2O_3 and hard materials with diamond or SiC grit.
44. .... is an abrading process, efficient in surface refining of cylindrical, flat, spherical and cone shaped parts.
45. Superfinishing produces a high wear resistant surface on any object which is symmetrical.
46. A very small amount of material is removed in polishing.
47. The dimensional accuracy of the parts is not affected by polishing and buffing operations.
48. Negligible amount of material is removed in buffing.
49. .... is an operation by which a bright, polished finish is produced on the surface of metal by rubbing action which smooths out small scratch marks.
50. Burnishing is generally used to produce a decorative finish.

ANSWERS

1. Grinding	**2.** Yes	**3.** Rough
4. No	**5.** Precision	**6.** Yes
7. Internal	**8.** Surface	**9.** Form
10. Yes	**11.** Grinding	**12.** Yes
13. self sharpening	**14.** No	**15.** No
16. Yes	**17.** grain	**18.** No
19. Yes	**20.** structure	**21.** Yes
22. Truing	**23.** Grinding	**24.** No
25. Centreless	**26.** Large	**27.** Yes
28. Yes	**29.** Surface	**30.** Yes
31. abrasive	**32.** Low	**33.** High
34. Yes	**35.** Glazed	**36.** Yes
37. No	**38.** Yes	**39.** Honing
40. Honing	**41.** hone	**42.** Lapping
43. Yes	**44.** Superfinishing	**45.** Yes
46. Yes	**47.** Yes	**48.** Yes
49. Burnishing	**50.** Yes.	

THEORETICAL QUESTIONS

1. Define the following terms :
   (*i*) Grinding;
   (*ii*) Rough grinding;
   (*iii*) Precision grinding.
2. How is "grinding" classified?
3. Discuss very briefly the following :
   (*i*) External cylindrical grinding.
   (*ii*) Internal cylindrical grinding.
   (*iii*) Surface grinding.
   (*iv*) Form grinding.
4. What are the advantages of grinding process over other cutting processes?
5. Enumerate the special features of grinding process.
6. How are grinding machines classified?
7. Explain with a neat sketch a plain cylindrical grinder.
8. Explain the working principle of the centreless grinding operation.
9. Explain briefly the three standard methods of feeding the work in centreless grinding.
10. What are the advantages and limitations of centreless grinding?
11. Explain the working principle of internal grinding.
12. Explain with a neat sketch 'centreless internal grinding'.
13. What is surface grinding? Explain.
14. Explain briefly with neat sketches various types of surface grinding machines.
15. What is disc grinding?
16. What is form grinding? Explain.
17. What is grinding wheel?
18. How is grinding ratio defined?
19. What is an abrasive? How are abrasives classified?
20. Explain briefly the following abrasives :
    (*i*) Silicon carbide (SiC)
    (*ii*) Aluminium oxide (Al_2O_3).
21. Discuss briefly the following :
    (*i*) Mounting of wheels.
    (*ii*) Wheel truing.
22. What is a 'bond'? Name and explain principal bonds.
23. What are the purposes of finishing surfaces of metal parts?
24. What is the purpose of honing? Give the examples of honing work.
25. What are the advantages and disadvantages of honing?
26. Explain briefly the 'lapping process'. Give the examples of lapping work.
27. Name the lap materials generally used.

28. How are lapping machines classified?
29. State the advantages and disadvantages of lapping.
30. What is superfinishing?
31. Explain briefly with a neat sketch the superfinishing operation.
32. In what respects the superfinishing operation basically differs from other abrasive finishing methods.
33 Give the comparison among lapping, honing and superfinishing.
34. Explain briefly 'Polishing' and 'Buffing'.
35. Write a short note on 'Burnishing'.
36. Give the comparison of grinding and finishing operations.

❑❑

12

Unconventional Machining Processes

12.1. INTRODUCTION

In conventional machining processes the ability of the cutting tool is utilised to stress the material beyond the yield point to start the material removal process. This requires that the cutting tool material be harder than the workpiece material. The advent of harder materials for aerospace applications have made the removal process by conventional methods very difficult as well as time consuming since the material removal rate reduces with an increase in hardness of the work material. Hence *machining processes which utilise other methods such as electro-chemical processes are termed as* **Unconventional or Non-traditional machining methods.**

The main **reasons** *for using non-traditional processes are :*

(*i*) *High strength alloys.*

(*ii*) *Complex surfaces.*

(*iii*) *High accuracies and surface finish.*

12.2 CLASSIFICATION OF UNCONVENTIONAL MACHINING METHODS

The unconventional methods can be broadly *classified* on the basis of the following criteria:

1. **Type of energy :**

(*i*) Chemical

(*ii*) Electro-chemical

(*iii*) Mechanical

(*iv*) Electrothermal.

2. **Mechanism of metal removal :**

(*i*) Shear

(*ii*) Erosion

(*iii*) Chemical ablation
(*iv*) Ionic dissolution
(*v*) Spark erosion
(*vi*) Vaporisation etc.

3. **Media for energy transfer :**
(*i*) Physical contact
(*ii*) High velocity particles
(*iii*) Reactive atmosphere
(*iv*) Electrolyte
(*v*) Hot gases
(*vi*) Electrons
(*vii*) Radiation etc.

4. **Source of energy :**
(*i*) Hydraulic or pneumatic pressure
(*ii*) Mechanical pressure
(*iii*) Corrosive agent
(*iv*) High current
(*v*) High voltage
(*vi*) Ionized gas etc.

- **Common Unconventional Machining Methods :**
1. Electrical Discharge Machining (EDM)
2. Electro-Chemical Machining (ECM)
3. Electro-Chemical Grinding (ECG)
4. Ultrasonic Machining (USM)
5. Electron Beam Machining (EBM)
6. Laser Beam Machining (LBM)
7. Plasma Arc Machining (PAM)
8. Abrasive Jet Machining (AJM)
9. Chemical Machining (CHM).

12.3. SELECTION OF PROCESS

For selecting a particular process the following common parameters should be taken into consideration :

1. Shape and size required to be produced.
2. Physical properties of the work material.
3. Process economy.
4. Process capabilities such as expected tolerance, surface finish, rate of metal removal, power requirement etc.).
5. Type of operation required (*e.g.*, cutting, hole making etc.)

Description of Unconventional Methods

12.4. ELECTRICAL DISCHARGE MACHINING (EDM)

Principle and Working : Refer to Fig. 12.1.

The **Electrical Discharge Machining (EDM)** *process involves controlled erosion of electrically conducting materials by the initiation of rapid and reptitive electrical discharge between the tool (cathode) and workpiece (anode) separated by a dielectric fluid medium.* A suitable gap between the tool and workpiece is maintained to cause the spark discharge. The gap can be varied to match the machining conditions such as metal removal rate.

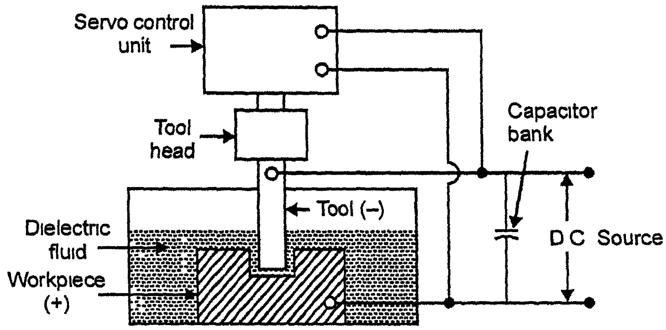


Fig. 12.1. Electric discharge machining (EDM).

As soon as the voltage gradient set up between the tool and the workpiece is sufficient enough to breakdown the dielectric medium, a conducting electrical path is developed for spark discharge owing to ionization of the fluid medium and thereby causes the current to flow. The temperature of the spot hit by the spark may rise upto 10000°C causing the work surface to melt and vaporize and ultimately to take the form of a sphere as it is quenched by the surrounding fluid.

If the tool is fed downwards, maintaining the predetermined gap, *the tool shape/profile will be reproduced on the workpiece.*

The spark gap, generally 0.01 to 0.1 mm, is adjusted so that the gap voltage is around 70 percent of the supply voltage for charging the capacitor bank. Higher gap although increases the discharge energy but it decreases the spark frequency due to increase in charging time of the capacitor.

The **'servocontrol unit'** is provided to *maintain the predetermined gap*. It senses the gap voltage and compares it with the preset value and the difference in voltage is then used to control the movement of servomotor to adjust the gap.

Important charcterstics of EDM :

- *Tool materials* : Copper, brass and graphite.
- *Workpiece materials* : Conducting metals and alloys.
- *Process parameters* : Voltage, capacitance, spark gap and melting temperature of workpiece.
- *Material removel* : Melting and vaporisation.

Advantages:

1. Machining time is *less* than conventional machining processes.
2. *Any complicated shape* that can be made on the tool can be reproduced on the workpiece.

3. The process can be applied to *all electrically conducting metals and alloys* irrespective of their melting points, toughness, hardness or brittleness.
4. Can be employed for *extremely hardened workpiece.*
5. Fragile and slender workpieces can be machined without distortion.
6. *Considerably easier and more economical polishing* can be done on the cratering type surfaces developed by EDM.
7. *Fine holes* can be easily drilled.
8. Enables high accuracy on tools and dies, because they can be machined in *'as hard'* condition.

Disadvatages :

1. Compared to conventional processes, *power required is very high.*
2. In some materials, *surface cracking* may take place.
3. Sharp corners *cannot* be produced.
4. Removal rate of material is low.
5. Surface tends to be rough for larger removal rates.
6. It cannot be applied to non-conducting materials.

Applications:

1. Very useful in *tool manufacturing* due to ease with which hard metals and alloyed can be machined.
2. Resharpening of cutting tools and broaches, trepanning of holes with straight or curved axes.
3. Machining of cavities for dies and remachining of die cavities without annealing
   - This process can be *used to preform almost all conventional machining operations.*

12.5. ELECTRO-CHEMICAL MACHINING (ECM)

Principle and Working : Refer to Figs. 12.2, 12.3.

It is an inherently versatile process of machining because of its capability of stress free machining of various kinds of metals and alloys. *It can produce shapes and cavities which are costly and extremely difficult to machine with the conventional machining processes and a true shape of the tool (or cathode) can be made on the workpiece (or anode) by controlled dissolution of anode of an electrolytic cell.*

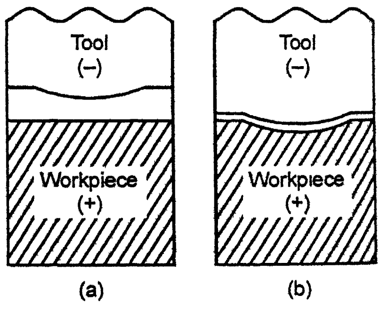


Fig. 12.2. The principle of ECM process (a) Shape of workpiece before machining; (b) Tool shape is reproduced on workpiece after ECM.

An electrolyte (usually a neutral salt solution such as sodium chloride, sodium nitrate, sodium chlorate) is passed through a very small gap (0.05 to 0.03 mm) created between the workpiece (or anode) and the tool (or cathode) whereas a direct current flow is made between them. When sufficient electrical energy (about 6 eV) is available, a metallic ion may be pulled out of the workpiece surface. The positive metallic ions will react with negative ions present in the

electrolytic solution forming metallic hydroxides and other compounds. Hence the metal will be anodically dissolved with the formation of sludges and precipitates. *The metal removal rate is governed by Faraday classical laws of electrolysis.*

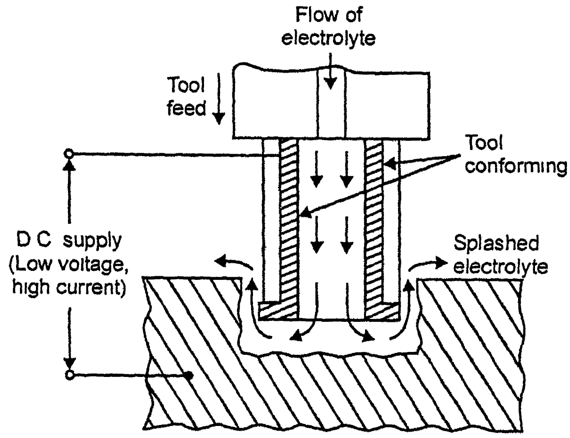


Fig. 12.3. Set up for Electro-Chemical Machining (ECM).

Characteristics of ECM :

- *Tool materials* . Copper and brass.
- *Workpiece materials* : Conducting metals and alloys.
- *Process parameters* : Current, voltage, feed rate and electrolyte.
- *Material removal* : Electrolysis.

Advantages :

1. The process is capable of machining metals and alloys irrespective of their strength and hardness.
2. Fragile parts, which are otherwise not easily machinable can be shaped by ECM.
3. Intricate and complex shapes can be machined easily through this process.
4. Metal removal rate is quite high in comparison to traditional machining, specially in respect of high tensile and high temperature resistant materials.
5. Wear on tool is insignificant or (say) almost non-existent.
6. With the application of this process, many machining operations, like grinding, milling, polishing etc. can be dispensed with.
7. No cutting forces are involved in the process.
8. The machined work surface is free of stresses.
9. High surface finish of the order of 0.1 to 0.2 microns can be obtained.
10. It is an accurate process and close tolerances of the order of 0.05 mm can be easily obtained.

Disadvantages :

1. Non-conductive materials cannot be machined.
2. The process cannot be used to machine sharp interior edges and corners less than 0.2 mm radius because of very high current densities at those points.
3. Very high power consumption.
4. Larger floor space is required.
5. A constant monitoring is required to suitably vary the tool feed rate and supply pressure of electrolyte so as to avoid formation of cavitation.
6. Designing and fabrication of tools is relatively more difficult.
7. High initial investment.
8. Specially designed fixtures are required to hold the workpiece in position, because it may be displaced due to the pressure of the inflowing elecrolyte.

9. Corrosion and rusting of workpiece, machine tools, fixtures etc., by electrolyte is a constant menance.

12.6. ELECTRO-CHEMICAL GRINDING (ECG)

Based on electro-chemical machining process and refinement to it, the process of electrolytic grinding has been developed in which *metal is removed by electro-chemical deposition (about 90%) and abrasion of metal (about 10%).* Thus the wear is very less.

Principle and Working :

Figure 12.4 shows a typical setup for Electro-Chemical Grinding (ECG).

The *grinding wheel* is mounted on a *spindle* which rotates inside suitable bearings. The *workpiece* is held on the *machine table* in suitable fixtures. The table can be moved forward and backward to feed the work or to withdraw it. *The grinding wheel and spindle are insulated from the rest of the machine* by using *an insulating sleeve,* as shown in the figure.

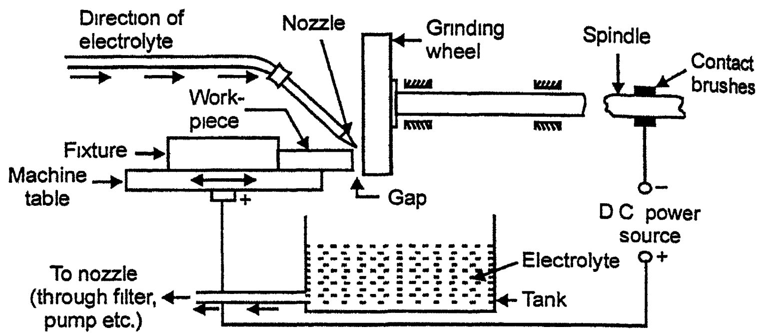


Fig. 12.4. Electro-Chemical Grinding (ECG).

Electrolyte from the *tank* is pumped into gap between the wheel and the workpiece. Current flows from the *cathode* (*grinding wheel*) to the *anode* (*workpiece*) through the electrolyte. *This leads to an electrochemical oxidation on the work surface. The oxide film so formed is removed by the grinding wheel, producing a highly accurate and finished surface.*

Advantages :

1. Fairly good surface finish obtained (surface finish of 0.05 to 1 μm CLA is possible).
2. Accuracy of the order of 0.01 mm can be achived by proper selection of wheel grit size and abrasive particles.
3. Negligible wear of the tool (grinding wheel).
4. Increased wheel life.
5. Considerable saving in wheel dressing time, as it is not required to be dressed very frequently.
6. As compared to conventional grinding, a very little cutting force is applied to the workpiece.
7. Since the heat is not generated in the process therefore work is free of surface cracks.
8. Work material is not subjected to any structural changes.

Disadvantages :

1. Metal removal rate is very low (of the order of 15 mm^3/s).
2. Power consumption is high.
3. Only electrically conductive materials can be machined.
4. Preventive measures are always required against corrosion by the electrolyte.
5. High initial cost.

Applications :

1. This process is *best suited for very precision grinding of hard metals like tungsten carbide tool tips* as the grinding pressure is very less and the temperature is very low due to which the defects like grinding cracks, tempering of work transformation of layers and dimensional control difficulties are eliminated.
2. Cutting thin sections of hard materials without danger of any damage or distortion.

12.7. ULTRASONIC MACHINING (USM)

Ultrasonic machining *is a process in which material is removed due to the action of abrasive grains.*

Principle and Working :

Refer to Fig. 12.5.

The abrasive particles are driven into the work surface by a tool oscillating normal to the work surface at high frequency. The tool is made of soft material, oncillated at frequencies of the order of 20 to 30 kHz with an amplitude of about 0.02 mm. It is pressed against the workpiece with a load of a few kg and fed downwards continuously as the cavity is cut in the work. The tool is shaped as the approximate mirror image of the configuration of the cavity desired in the work.

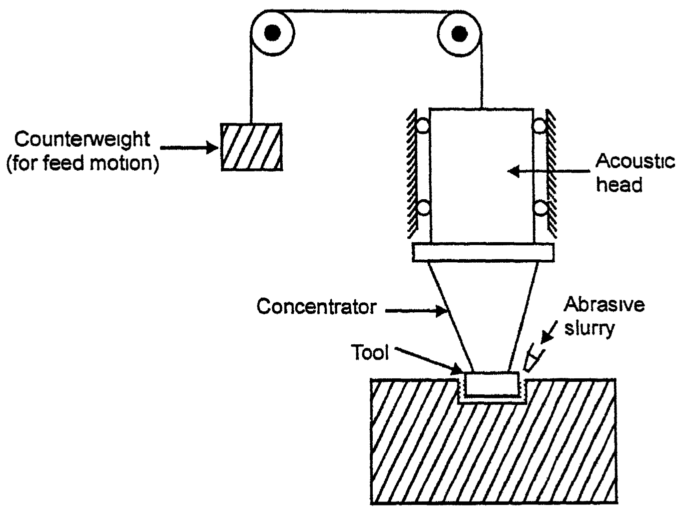


Fig. 12.5. Ultrasonic Machining (USM).

The *acoustic head* consists of a high frequency generator, a magnetostrictive transducer which converts mechanical motion into high vibration and transmits it to the tool. The counterweight with rope and pulley arrangement provides the feed machanism and is designed to apply the working force during machining.

Characterstics of USM :

- *Tool materials*: Brass and mild steel.
- *Work materials:* Hard and brittle materials like semiconductors, glass and ceramics.
- *Process parameters*: Frequency, amplitude, grain size, slurry concentration and feed force.

- *Material removal*: Fracture of work material due to impact of grains.
- *Abrasive*: Aluminium oxide, silicon carbide and boron carbide.
- *Grain size*: Mesh-size 100-800.
- *Gap*. 0.2 to 0.5 mm.

Advantages :

1. Noiseless operation.
2. Low metal removal cost.
3. Extremely hard and brittle materials can be easily machined.
4. Operation of the equipment is quite safe.
5. Highly accurate profiles and good surface finish can be easily obtained.
6. Because of no heat generation in the process, the physical properties of the work material remain unchanged
7. The machined workpieces are free of stresses.

Disadvantages :

1. High tooling cost.
2. Low metal removal rate.
3. The size of the cavity that can be machined is limited.
4. High power consumption.
5. The initial equipment cost is higher than the conventional machine tools.
6. The process is unsuitable for heavy metal removal.
7. For maintaining an efficient cutting action the slurry may have to be replaced periodically.
8. It is difficult to machine softer materials.

Applications :

1. Several machining operations like turning, threading, grinding, milling etc.
2. Machining of hard to machine and brittle materials.
3. Dentistry work-to drill fine holes of desired shape in teeth.
4. Tool and die making, specially wire drawing and extrusion dies.

12.8. ELECTRON BEAM MACHINING (EBM)

Electron beam machining *is a process of machining materials with the use of a high velocity beam of electrons*. This process is best suited for *microcutting of material* (in mg/s) because the evaporated area is function of the beam power and the method of focusing which can be easily controlled.

Principle and Working :

Refer to Fig. 12.6.

In this process the material is removed with the help of a high velocity (travelling at half the speed of light, *i.e.*, 160,000 km/s) focused stream of electrons which are focused magnetically upon a very small area. These electrons heat and raise the temperature locally above the boiling point and thus melt and vaporise the work material at the point of bombardment.

The electrons are obtained in free state by heating the cathode metal in *vacuum* to the

temperature at which they attain sufficient speed for escaping to the space around the cathode. These can then be made to move under the effect of electric or magnetic field and can be accelerated greatly. The acceleration is carried out by electric field and focusing and concentration is done by controllable magnetic fields.

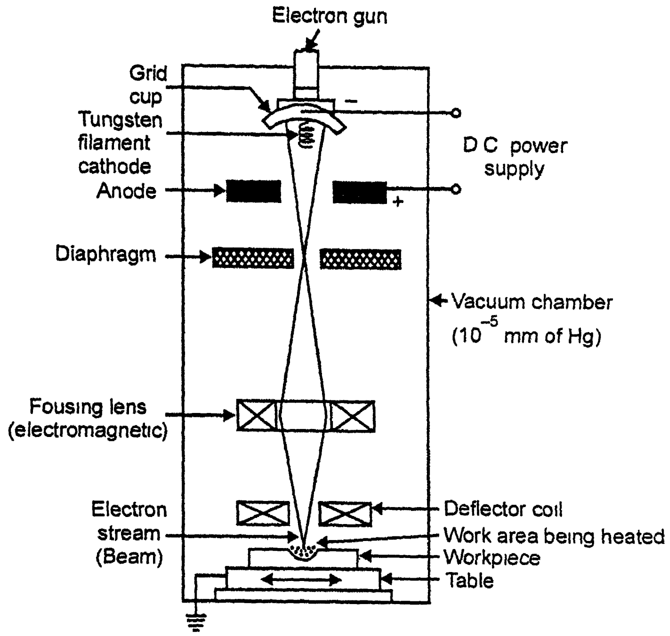


Fig. 12.6. Set up for Electron Beam Machining (EBM).

Characteristics of EBM :

- *Workpiece materials :* All materials.
- *Material removal :* High speed electrons impinge on surface and K.E. of electrons produces intense heating to melt or vaporise the metal.
- *Voltage :* 150 kV.
- *Power density :* 6500 billion W/mm^2
- *Medium :* Vacuum (10^{-5} mm of Hg)
- *Specific power consumption :* 500 W/mm^3 min.

Advantages :

1. It is excellent strategy for micro-machining. It can drill holes or cut slots which cannot be otherwise made.
2. It can cut any known material, metal or non-metal that would exist in vacuum.
3. No physical or metallurgical damage.
4. There is no contact between the work and tool.
5. Heat can be concentrated on a particular spot.
6. Close dimensional tolerances can be a achieved because problem of tool wear is non-existent.

Disadvantages :

1. Low metal removal rate.
2. High equipment cost.
3. High operator skill required.
4. Only small cuts are possible.
5. High power consumption.
6. Unsuitable for producing perfectly cylindrical deep holes.
7. Workpiece size is limited due to requirement of vacuum in the chamber

Applications :

1. Micro-machining operations on workpieces of thin sections.
2. Micro-drilling operations (upto 0.002 mm) for thin orifices, dies for wire drawing, parts of electron microcopes, fibre spinners, injector holes for diesel engines etc.
3. Very effective for machining of metals of low heat conductivity and high melting point.

12.9. LASER BEAM MACHINING (LBM)

The word LASER stands for "Light Amplification using Stimulated Emission of Radiation". Laser provides intense and unidirectional beam of light; this light is coherent in nature. The machining by which a laser beam removes material from the surface being worked *involves a combination of the melting and evaporation processes*. However with some materials the machanism is purely one of evaporation.

Principle and Working :

The principle utilised in LBM is that under proper conditions light energy of a particular frequency is utilised to stimulate the electrons in an atom to emit additional light with exactly the same characteristics of the original light source.

Figure 12.7 shows the set-up for Laser Beam Machining. The laser beam is focused with the help of the lens and the workpiece is placed near the focal point of the lens. A short pulse of laser melts and vaporises the material. The explosive escape of the vaporised metal helps in removing most of the molten metal from the hole as tiny droplets. Any of the molten metal not removed will be resolidified along the walls of the hole.

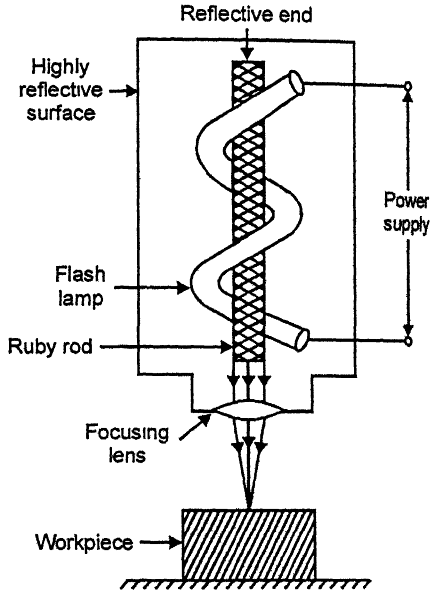


Fig. 12.7. Laser Beam Machining (LBM).

Characterstics of LBM :

- *Tool :* High powered focused laser beam.
- *Workpiece materials :* Any material.
- *Process parameters :* Power intensity of laser beam, focused diameter of laser beam and melting temperature of workpiece material.
- *Material removal* : Melting and vaporisation.
- *Medium* : Air.

Advantages :

1. No mechanical contact between the tool and the work.
2. The beam can be projected through a transparent window.
3. The laser can be used with materials sensitive to heat shock such as ceramics.
4. The workpiece is not subjected to large mechanical forces.

5. The laser operates in any transparent environment including air, insert gas, vacuum and even certain liquids.
6. Can be effectively used for welding of dissimilar metals as well.
7. Very small holes and cuts can be made with fairly high degree of accuracy.
8. Any material can be easily machined irrespective of its structure and physical and mechanical properties.

Disadvantages :

1. The laser system is quite inefficient.
2. Low production rate.
3. High capital investment required.
4. Its application is limited to only thin sections and where a very small amount of metal removal is involved.
5. Cannot be effectively used to machine highly heat conductive and reflective materials.
6. Highly skilled operators are needed.

Applications :

1. Trimming of sheet metal plastic parts and carbon resistors.
2. Cutting or engraving patterns on thin films.
3. Drilling small holes (upto 0.005 mm dia.) in hard materials like tungsten and ceramics.
4. Cutting complex profiles on thin and hard materials, *viz.*, films for making ICs.
   - Laser drilled holes exhibit a taper and also lack a high degree of roundness. Holes larger than 1.25 mm cannot be drilled because the power density decreases. Hence *laser cutting is more often used than laser drilling*. In a laser cutting opeation a high velocity gas jet is used in conjunction with the laser beam. The gas jet helps to rapidly remove the metal from the hole.

12.10. PLASMA ARC MACHINING (PAM)

A **plasma** is *a high temperature ionized gas*. The plasma arc machining is done with a high speed jet of a high temperature plasma.

Principle and Working :

A plasma is generated by subjecting a flowing gas to the electron bombardment of an arc. For this, the arc is set up between the electrode and the anodic nozzle; the gas is forced to flow through this arc (Fig.12.8). The high velocity electrons of the arc collide with the gas molecules,

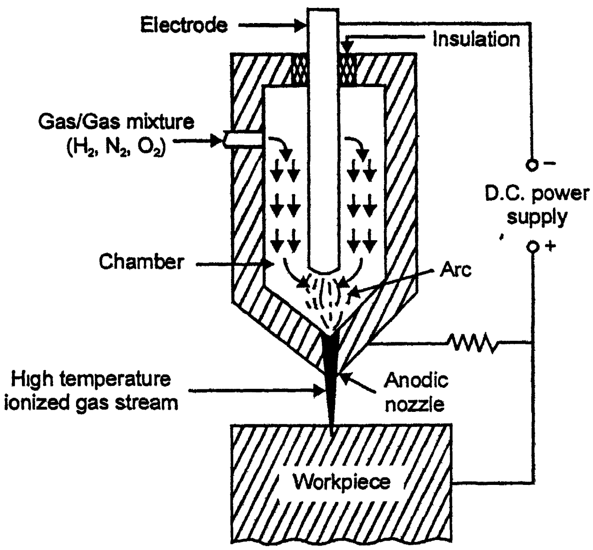


Fig. 12.8. Plasma Arc Machining (PAM).

causing a dissociation of the diatomic molecules or atoms into ions and electrons melting in a substantial increase in the conductivity of the gas which is now in plasma state. The free electrons subsequently accelerate and cause more ionization and heating. Afterwards a further increase in temperature takes place when the ions and free electrons recombine into atoms or when the atoms recombine into molecules as these are exothermic processes. So a *high temperature plasma is generated which is forced through the nozzle in the form of a jet.* This jet (ionized steam of gas) is impinged on the workpiece which gets melted and eroded.

Characterstics of PAM :

- *Tool :* Plasma jet (Maximum velocity = 500 m/s).
- *Workpiece materials :* All conducting materials.
- *Material removel* : Melting (Maximum material removal rate = 150 cm^3/min).
- *Medium* : Plasma.
- *Maximum temperature* : 16000°C.
- *Power range* : 2 to 200 kW.
- *Critical parameter* : Voltage (30 to 250 V); Current (upto 600 A); electrode gap; nozzle dimensions; melting temperature.

Advantages :

1. Excessively high temperatures are generated for use.
2. Can be used to cut any metal.
3. A faster process.

Disadvantages :

1. Initial cost of equipment is quite high.
2. Adequate safety precautions are always needed for the operator.
3. The work surface may undergo some metallurgical changes.

Applications :

1. Cutting of stainless steel and non-ferrous metals (such as aluminium alloys).
2. Turning and milling of 'hard to machine' materials.

12.11. ABRASIVE JET MACHINING (AJM)

Principle and Working : Refer to Fig. 12.9.

This process consists of directing a stream of fine abrasive grains, mixed with compressed air or some other gas at high pressure through a nozzle on to the surface of the workpiece to be machined. These particles impinge on the work surface at high speed and the erosion caused by their impact enables the removal of metal. *The metal removal rate depends upon the flow rate and size of abrasive particles.*

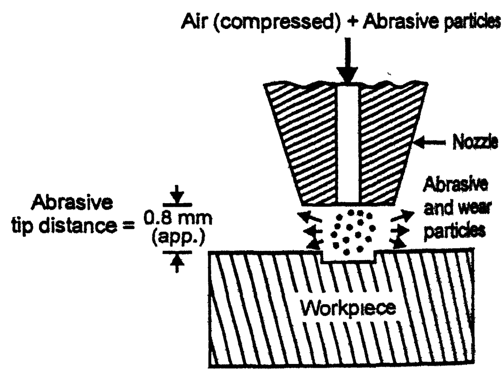


Fig. 12.9. Abrasive Jet Machining (AJM).

— The abrasives may be Al_2O_3, SiC, sodium bicarbonate, dolomite, glass beads etc. The abrasive particles should have irregular shape consisting of short edges. Round particles are useless. Their size is 10 to 50 microns. The carrier is usually air, CO_2 or N_2.

Characteristics of AJM :

- *Material removal* : By impinging abrasive grains at high speed.
- *Critical parameters* : Abrasive flow rate and velocity, nozzle tip distance, abrasive grain size.

Advantages :

1. Low capital investment required.
2. Brittle materials of thin sections can be easily machined.
3. Intricate cavities and holes of any shape can be machined in materials of any hardness.
4. There is no direct contact between the tool and workpiece.
5. Normally inaccessible portions can be machined with fairly good accuracy.

Disadvantages :

1. Low metal removal rate.
2. Unsuitable for machining of ductile materials.
3. The abrasive powder used in the process cannot be reclaimed or reused.
4. Machining accuracy is relatively poorer.
5. There is always a danger of abrasive particles getting embedded in the work material. Hence cleaning needs to be necessarily done after the operation.

Applications :

1. Machining of intricate profiles on hard and fragile materials.
2. Fine drilling and micro-welding.
3. Frosting and abroading of glass articles.
4. Aperture drilling for electronic microscopes.
5. Machining of semiconductors.

Note : This process should not be misunderstood as *sand blasting* because this process is *basically meant for metal removal with the use of small abrasive particles*, whereas the sand blasting process is a surface cleaning process which *does not involve any metal cutting*.

12.12. CHEMICAL MACHINING (CHM)

Chemical machning *is a process used to dissolve the workpiece material in chemial solutions.* Metal can be removed from selected portions or from the entire surface of the workpiece, according to requirement. If selective machining is desired, the portions required to be left unmachined are covered with a resistant material called a *'resist'* or *'maskant'* which can be stripped away after machining.

The chemical machining process can be *classified* as follows :

1. **Chemical blanking.** It is used for cutting out parts from thin sheet metal.
2. **Chemical contour machining.** It is also known as '*Chemical milling*' and is employed for selective or overall metal removal from thicker workpieces.
3. **Chemical engraving.**

A typical chemical operation entails the following steps :

(*i*) Clean the workpiece thoroughly so as to ensure that the masking material will adhere to the workpiece well to reduce any possibility of stray etching due to *maskant* debonding.

(*ii*) Apply a chemical resistant mask on the workpiece surface where no material is to be removed.

(*iii*) Dip the workpiece into the chemical solution called *etchant* and leave it for sufficient time to get the necessary depth of etching. The strength of the etching is maintained since it becomes weak by absorbing the workpiece material with time.

(*iv*) Remove the mask and clean the workpiece.

Advantages :

1. Very low tool cost.
2. Low design change cost.
3. Complex contours can be easily machined.
4. Tooling time is substantially reduced.
5. Both faces of the workpiece can be machined simultaneously.
6. The part produced is free of burrs.
7. Hard and brittle materials can be machined.
8. It is a flexible process from design point of view.

Disadvantages :

1. It is a slow process, since the metal removal rate is low.
2. Larger floor space is required.
3. Skilled operators are needed.
4. Sharp corners cannot be produced.
5. High manufacturing cost.
6. Metal thickness that can be machined is limited.

Applications :

Chemical machining is generally used when *very small amounts of material are to be removed from the surface in any application.* In *aerospace application* a large volume of unwanted material is removed from the surface to reduce the weight, thereby increasing the strength to weight ratio which is conveniently done with chemical machining.

12.13. COMPARISON OF UNCONVENTIONAL MACHINING METHODS

The comparison of Unconventional machining methods is given (in tabular form) below :

TABLE 12.1

Comparison of Unconventional Machining Methods

S.No.	*Process*	*Material removal rate (mm^3/s)*	*Dimensional accuracy (μm)*	*Surface finish (μm)*	*Capital cost*	*Power consumption (kWh)*
1.	*Electric Discharge Machining (EDM)*	·10-20	15-50	0.2-2.5	Medium	2-4
2.	*Electro-Chemical Machining (ECM)*	200-300	15-100	0.1-2.5	Very high	100-150
3.	*Ultrasonic Machining (USM)*	5-10	7-15	0.2-2.5	Low	2-3
4.	*Laser Beam Machining (LBM)*	0.001-0.002	10-100	0.5-1.5	Low/medium	0.003-0.005
5.	*Chemical Machining (CHM)*	0.15-30	25-100	0.5-2.5	Medium	—

QUESTIONS WITH ANSWERS

Q. 12.1. Explain briefly 'Water Jet Machining'.

Ans. In 'Water Jet Machining' process a high velocity *water jet* is made to impinge on to the workpiece. This jet pierces the work material and performs a sort of slitting operation. Water under pressure from a hydraulic accumulator is passed through the office of a nozzle to increase its velocity. The nozzle orifice size (dia.) usually varies from 0.08 mm to 0.5 mm and the exit velocity of the water jet from the nozzle varies upto 920 m/s. These high velocity jets can be used to cut relatively softer and non-metalic materials like paper boards, wood, plastics, asbestos, rubber, fireglass, leather etc.

- A variation of this process known as *"Hydrodynamic Jet Machining (HJM)"* has been successfully used to machine almost all types of ferrous and non-ferrous metals and alloys.

Q. 12.2. For what types of works the Electro-Chemical Grinding (ECG) is best suited?

Ans.
- ECG is best suited for grinding *multiple-tooth milling cutters, carbide tipped tools and tool bits.*
- As it puts very little pressure on work it is best suited for grinding fragile and not easily supported works, like grinding slots, flats and forms in thin-walled fragile workpieces.

Q. 12.3. On what types of works the process of chemical machining is best suited and what are its advantages and limitations?

Ans.
- Chemical machining is an excellent method of getting complex shapes on very thin and most difficult to machine tools.

- It does not require any press or punch or die. It does not distort the workpiece and no burrs are produced.
- It is a *slow process* and thus limited to machining metals upto 3 mm thickness and not used for producing large quantities.

Q. 12.4. What is 'hot machining'?

Ans. 'Hot Machining' *is used for machining high strength, high hardness and high temperature resistant materials which are difficult to machine at room temperature.*

Machining of hard metals at elevated temperature is applied mainly to *turning and milling operations*. Since the shear strength of metal decreases at elevated temperature as compared to that at room temperature the magnitude of the cutting forces on the tool is lower. Further as the chip formation by plastic deformation in the shear plane ahead of tool becomes easier at elevated temperature and cutting forces involved are less, therefore *power requirements are low*. But as the property of tool material at elevated temperature is also changed due to its being in contact with high temperature material, therefore tool life is also affected. It is found that tool life is maximum for certain temperature of workpiece (for particular work material and tool material) at which total metal removal rate per tool grinding will be maximum irrespective of the speed.

Q. 12.5. For what purpose Electric Discharge Machines (EDM) are used?

Ans. EDM machines are used for avoiding difficulty to machine materials through the use of electric spark.

Example : Die sinking or removal of broken tools embedded in workpieces.

Q. 12.6. Indicate the sources of energy in the following processes :
(*a*) EDM, (*b*) USM, (*c*) LBM, (*d*) ECM.

Ans.	*Process*	*Source of energy*
(*a*)	EDM	*Electric spark*
(*b*)	USM	*Mechanical*
(*c*)	LBM	*Radiation*
(*d*)	ECM	*Electrical*

Q. 12.7. What is 'Magnetic Forming' ?

Ans. *'Magnetic Forming'* is also known as 'magnetic pulse forming' or 'electromagnetic forming'.

In this process an insulated induction coil is either wrapped around or placed within the work depending upon whether the metal is to be squeezed inward or buldged outward. The high momentary current is passed through the coil which *develops intense magnetic field* causing the work to collapse, compress, shrink or expand depending on the design and placement of the coil.

The work size, that can be forced, is determined by the energy storage capacity and ability of the unit to utilize that energy. High conductivity materials can be formed if they are wrapped or coated with a high conductivity auxiliary material.

HIGHLIGHTS

1. The main reasons for using non-traditional processes are :
   (*i*) High strength alloys.
   (*ii*) Complex surfaces.
   (*iii*) High accuracies and surface finish.
2. Common *"Unconventional Machining Methods"* are :
   (*i*) Electrial Discharge Machining (EDM)
   (*ii*) Electro-Chemical Machining (ECM)
   (*iii*) Electro-Chemical Grinding (ECG)
   (*iv*) Ultrasonic Machining (USM)
   (*v*) Electron Beam Machining (EBM)
   (*vi*) Laser Beam Machining (LBM)
   (*vii*) Plasma Arc Machining (PAM)
   (*viii*) Abrasive Jet Machining (AJM)
   (*ix*) Chemical Machining (CHM)

OBJECTIVE TYPE QUESTIONS

A. Choose the Correct Answer :

1. Which of the following is an advantage of 'Laser beam machining'?
   (*a*) Laser beam can be sent to longer distances without diffraction.
   (*b*) There is no contact between tool and workpiece.
   (*c*) Heat treated and magnetic particles can be welded without losing their properties.
   (*d*) None of the above.
2. For machining materials of high hardness material selected for tool in EDM should be
   (*a*) hard
   (*b*) soft
   (*c*) any material with good electrical conductivity
   (*d*) none of the above.
3. Surface finish produced by electrochemical grinding on 'Tungsten carbide' can be expected to be of the order of.... micron.
   (*a*) 0.1 to 0.2 (*b*) 0.2 to 0.4
   (*c*) 0.4 to 0.8 (*d*) 0.8 to 0.9.
4. .... governs metal removal rate in electrochemical machining
   (*a*) Fleming's rule (*b*) Newton's law
   (*c*) Faraday's law (*d*) None of the above.
5. Ultrasonic machining is based on
   (*a*) uniform heating (*b*) uniform grinding
   (*c*) vibratory waves of high frequency (*d*) uniform machining
   (*e*) None of the above.

6. In ultrasonic machining the rate of penetration is dependent on
   (*a*) action of slurry (*b*) action of abrasive grains
   (*c*) reduction of a chemical (*d*) all of these.
7. In ultrasonic machining, the rate of penetration is dependent on
   (*a*) flow path (*b*) slurry
   (*c*) area of tool tip (*d*) all of these.
8. In ultrasonic machining, longitudinal waves are preferred because they
   (*a*) can travel at a high velocity
   (*b*) are easily generated
   (*c*) can be propagated in solid, liquid and gases
   (*d*) all of the above.
9. Tool tip is attached to the tool cone by
   (*a*) welding (*b*) press fitting
   (*c*) silver soldering (*d*) nut and bolt
   (*e*) none of the above.
10. .... process is used for making a complicated contour in a carbide piece.
    (*a*) Laser machining (*b*) Electro-chemical milling
    (*c*) Plasma-arc machining (*d*) Electro-discharge machining
    (*e*) None of the above.
11. Slurry used in USM is
    (*a*) alkaline only (*b*) alcohol based
    (*c*) mercury based (*d*) water based
    (*e*) none of the above.
12. Erosion of metal in EDM is
    (*a*) proportionate to the number of sparks
    (*b*) continous
    (*c*) either of the above
    (*d*) none of the above.
13. AJM is used for
    (*a*) plastics only (*b*) ductile materials only
    (*c*) brittle materials only (*d*) any of the above.
14. In USM, slurry is fed by
    (*a*) a high power pump (*b*) manual system
    (*c*) any of the above (*d*) none of these.
15. Selection of proper tool material in EDM is influenced by which of the following parameters?
    (*a*) Tolerance required
    (*b*) Volume of material to be removed
    (*c*) Size of the electrode
    (*d*) Surface finish required
    (*e*) None of the above.

16. Time required for machining by EDM in comparison to the conventional machining is

(*a*) less (*b*) equal

(*c*) more (*d*) unpredictable.

17. In EDM, metal removal rate is proportional to

(*a*) frequency of charging

(*b*) energy delivered in each spark

(*c*) both (*a*) and (*b*)

(*d*) none of these.

18. Abrasive jet machining uses a jet of

(*a*) abrasive particles suspended in oil

(*b*) fine grained abrasive particles mixed with air or some other carrier gas at high pressure

(*c*) abrasive particles suspended in water

(*d*) none of the above.

19. Abrasive jet machining is used for

(*a*) cutting thin sectioned fragile components made of glass, refractories, ceramics, mica etc.

(*b*) removing flash and parting lines from injection moulded parts

(*c*) deburring and polishing plastic, nylon and teflon components

(*d*) all of the above.

20. In ultrasonic machining, tool used

(*a*) oscillates at a frequency of 20 to 30 kHz

(*b*) has the shape exactly to that of a hole to be made

(*c*) is made of soft material

(*d*) all of the above.

21. .... machining process needs high velocity stream of electrons for its operation.

(*a*) Abrasive jet (*b*) Ultrasonic

(*c*) Electro-discharge (*d*) Electron-beam.

22. In abrassive jet machining (AJM), metal removal takes place due to

(*a*) machining (*b*) grinding

(*c*) metal erosion (*d*) all of the above.

(*e*) None of the above.

23. What is the principle of 'Water jet machining' (WJM)?

(*a*) Air and water mix jet is used.

(*b*) Surface is dipped in the water.

(*c*) A jet of water is directed on the surface at a high velocity.

(*d*) None of the above.

24. In electro-discharge machining (EDM), metal removal takes place as

(*a*) chemical reaction of metal (*b*) dissolution of metal

(*c*) erosion of metal (*d*) none of these.

25. In electrolytic grinding, metal removal takes place by
(*a*) erosion (*b*) corrosion
(*c*) electro-chemical action (*d*) all of these.

26. In EDM, the required property of tool is
(*a*) resistivity (*b*) dielectric strength
(*c*) conductivity (*d*) none of these.

27. LASER welding finds wide applications in
(*a*) electronic industry (*b*) heavy industry
(*c*) structural work (*d*) none of these.

28. LASER is produced by
(*a*) aluminium (*b*) ruby
(*c*) diamond (*d*) graphite.

29. For converting electrical energy into mechanical energy, which of the effects form the basis of USM?
(*a*) Chemical action (*b*) Photosynthesis
(*c*) Piezoelectric effect (*d*) Any of these.

ANSWERS

1. (*d*)	**2.** (*c*)	**3.** (*b*)	**4.** (*c*)	**5.** (*c*)
6. (*b*)	**7.** (*d*)	**8.** (*d*)	**9.** (*c*)	**10.** (*d*)
11. (*d*)	**12.** (*a*)	**13.** (*c*)	**14.** (*c*)	**15.** (*e*)
16. (*a*)	**17.** (*c*)	**18.** (*b*)	**19.** (*d*)	**20.** (*d*)
21. (*d*)	**22.** (*c*)	**23.** (*c*)	**24.** (*c*)	**25.** (*c*)
26. (*c*)	**27.** (*a*)	**28.** (*b*)	**29.** (*c*).	

B. Fill in the Blanks or Say 'Yes' or 'No' :

1. The .... process involves controlled erosion of electrically conducting materials by the initiation of rapid and repetitive electrical discharges between the tool and workpiece separated by a dielectric fluid medium.
2. In EDM the .... unit is provided to maintain the predetermined gap.
3. In EDM the machining time is .... than conventional machining process.
4. Fine holes cannot be drilled by EDM.
5. EDM can be employed for extremely hardened workpiece.
6. In EDM the material removing is by melting and vaporisation.
7. In .... the metal removal rate is governed by Faraday classical laws of electrolysis.
8. Tool materials in ECM are copper and brass.
9. In ECM process metal removal rate is quite low.
10. Non-conductive materials can be machined by ECM process.
11. In case of ECM the power consumption is very high.
12. In case of ECM smaller floor space is required.
13. In ECM designing and fabrication of tools is relatively more difficult.
14. ECG process is best suited for very precision grinding of hard metals like tungsten carbide tool tips.

15. In case of ECG the wear of tool is ....
16. In ECG process power consumption is ....
17. In ECG metal removal rate is very low.
18. .... machining is a process in which material is removed due to the action of abrasive grains.
19. In case of USM the tool materials are brass and mild steel.
20. USM is a noisy operation.
21. In case of USM the metal removal cost is ....
22. In case of USM tooling cost is high.
23. .... is a process of machining materials with the use of a high velocity beam of electrons.
24. In EBM the medium of working is ....
25. In EBM close dimensional tolerances can be achieved.
26. In EBM only small cuts are possible.
27. In EBM process the metal removal rate is high.
28. In LBM the material removal is by melting and vaporisation.
29. Any material can be easily machined by LBM process.
30. A .... is a high temperature ionized gas.
31. In PAM the material removal is by ....
32. PAM is a faster process.
33. In AJM the material removal is by impinging abrasive grains at high speed.
34. In AJM machining accuracy is relatively ....
35. AJM is unsuitable for machining of ductil materials.
36. .... machining is a process used to dissolve the workpiece material in chemical solutions.
37. Chemical .... is used for cutting out parts from thin sheet metal.
38. Chemical .... is employed for selective or overall metal removal from thicker workpieces.
39. Chemical machining has a very low tooling cost.
40. Chemical machining is a .... process.

ANSWERS

1. EDM	**2.** servo-control	**3.** less
4. No	**5.** Yes	**6.** Yes
7. ECM	**8.** Yes	**9.** No
10. No	**11.** Yes	**12.** No
13. Yes	**14.** Yes	**15.** negligible
16. high	**17.** Yes	**18.** Ultrasonic
19. Yes	**20.** No	**21.** low
22. Yes	**23.** EBM	**24.** vacuum
25. Yes	**26.** Yes	**27.** No

28. Yes	**29.** Yes	**30.** plasma
31. melting	**32.** Yes	**33.** Yes
34. poorer	**35.** Yes	**36.** Chemical
37. blanking	**38.** milling	**39.** Yes
40. slow.		

THEORITICAL QUESTIONS

1. What do you understand by the term "Unconventional or Non-traditional machining methods? What is their importance ?
2. Explain why unconventional machining processes are used?
3. How are 'Unconventional machining methods' classified?
4. What are the main parameters to be considered while selecting a particular process and why?
5. What is "Electrical Discharge Machining (EDM)"? Explain its principle with the help of a suitable diagram.
6. State the advantages, disadvantages and applications of EDM.
7. List the important characterstics of EDM.
8. Explain with a neal sketch the principle and working of Electro-Chemical Machining (ECM) process.
9. List the advantages, disadvantages and applications of ECM.
10. Give the important characterstics of ECM.
11. Describe briefly 'Electro-Chemical Grinding' process. State also it advantages, disadvantages and applications.
12. Explain briefly with a neat sketch the principle and working of Ultrasonic machining (USM) process/method. List also its advantages, disadvantages and applications.
13. Give the important characteristics of USM.
14. What is the working principle of Electron Beam Machining (EBM) ? What are its advantages, disadvantages and applications?
15. List the characterstics of EBM.
16. Describe briefly with a neat diagram the working principle of Laser Beam Machining (LBM)? Give also its advantages, disadvantages and applications.
17. What is a 'plasma'?
18. Explain briefly with a neat sketch the working principle of Plasma Arc Machining (PAM). State also its advantages, disadvantages and applications.
19. List the characteristics of PAM.
20. Explain clearly, with a neat diagram, Abrasive Jet Machining (AJM) method. State also its advantages, disadvantages and applications.
21. What is Chemical Machining? State its advantages and disadvantages.

❑❑

13

Fundamentals of Welding and Allied Processes

13.1 Introduction, 13.2. Advantages and disadvantages of welding, 13.3. Classification of welding processes, 13.4. Pressure welding : Forge welding — Resistance electric welding — Butt welding — Flash welding — Spot welding — Seam welding — Projection welding, 13.5. Fusion welding : Gas welding — Electric arc welding — Metallic arc welding — Carbon arc welding — Atomic hydrogen welding — Shielded arc welding — Thermit welding, 13.6. Modern welding techniques : Tungsten inert-gas welding (TIG) welding — Metal inert-gas welding (MIG) — Submerged arc welding — Electro-slag and electro-gas welding — Electron-beam welding — Ultrasonic welding — plasma arc welding — laser beam welding — Hydrodynamic welding — Cold welding, 13.7. Electrodes, 13.8. Welding of various metals, 13.9. Rebuilding, 13.10. Hardfacing, 13.11. Defective welds, 13.12. Underwater welding, 13.13. Defects in welds, 13.14. Testing of welded points, 13.15. Effect of welding on the grain size of the metal, 13.16. Soldering : Definition — types of solder — selection of solder — flux or soldering fluid — soldering equipment — soldering procedure — characteristics of a good joint — important tips for effective soldering operation — advantages of soldering — applications of soldering-types of soldered joints, 13.17. Brazing : Introduction — fluxes — brazing equipment — brazing procedure — applications of brazing — silver equipment — brazing procedure — applications of brazing — silver soldering, 13.18. Comparison of welding and allied processes, ***Questions with Answers*** *— Highlights — Objective Type Questions — Theoretical Questions.*

13.1. INTRODUCTION

- **Welding.** *It is method of joining metals by applications of heat, without the use of solder or any other metal or alloy having a lower melting point than the metals being joined.*

The large bulk of materials that are welded are metals and their alloys, although the term welding is also applied to the joining of other materials such as thermoplastics. Welding joins different metals/alloys with the help of a number of processes in which heat is supplied either electrically or by means of a gas torch. In order to join two or more pieces of metals together by one of the welding processes, the *most essential requirement is heat. Pressure may also be employed, but this is not, in many processes essential.*

- **Soldering.** *It is a process of joining two pieces of metal with a different flexible metal applied in a molten state.* The fusible metal is called *'solder'*.

- **Brazing.** *It is a process of joining two metal pieces in which a non-ferrous alloy is introduced in the liquid state between the pieces to be joined and allowed to solidify.*

13.2. ADVANTAGES AND DISADVANTAGES OF WELDING

Following are the *advantages and disadvantages* of welding :

Advantages :

1. A large number of metals/alloys both similar and dissimilar can be joined by welding.
2. Welding can join workpieces through spots, as continuous pressure tight seams, end-to-end and in a number of other configurations.
3. A good weld is as strong as the base metal.
4. Welding permits considerable freedom in design.
5. General welding equipment is not very costly.
6. Portable welding equipments are available.

Disadvantages :

1. Welding results in residual stresses and distortion of the workpieces.
2. Welding heat produces metallurgical changes. The structure of the welded joint is not same as that of parent metal.
3. Jigs and fixtures are generally required to hold and position the parts to be welded.
4. A welded joint, for many reasons, needs stress-relief heat treatment.
5. Welding results in residual stresses and distortion of the workpieces.
6. Welding gives out harmful radiations (light), fumes and spatter.
7. For producing a good welding job, a skilled worker is a must.

13.3. CLASSIFICATION OF WELDING PROCESSES

The welding processes may be *classified* as follows :

1. Pressure Welding :

(*i*) Forge welding

(*ii*) Resistance electric welding

- Butt welding
- Flash welding
- Spot welding
- Seam welding
- Projection welding.

2. Fusion Welding :

(*i*) Gas welding

(*ii*) Electric arc welding

- Metallic arc welding
- Carbon arc welding
- Atomic hydrogen welding
- Shielded arc welding.

(*iii*) Thermit welding.

Modern welding techniques :

(*i*) Tungsten inert-gas (TIG) welding
(*ii*) Metal inert-gas (MIG) welding
(*iii*) Submerged arc welding
(*iv*) Electro-slag and electro-gas welding
(*v*) Electron-beam welding
(*vi*) Ultrasonic welding
(*vii*) Plasma arc welding
(*viii*) Laser beam welding.

The various welding processes are discussed in detail in the following articles.

13.4. PRESSURE WELDING

The characteristics of a pressure weld is that the metal joined is *never brought* to a *molten stage*, it is heated to a welding temperature and the actual union is brought about *by application of pressure.*

(I) Forge welding.
(II) Resistance electric welding.

13.4.1. Forge Welding

- In this method of welding the surfaces to be joined are heated in an open hearth until they reach the welding temperature of metal, *which is below its melting point.* The blacksmith will judge this temperature by the colour of the metal, which may be between red-hot and white-hot. The parts are then placed on an anvil and hammered together.
- In this welding process there is a risk of oxide and other inclusion when the metal is heated in an open fire and accurate judgement of the temperature is called for if the structure of metal is not to be changed. Modern alloy steels can be ruined by injudicious heating. When the wide range of light alloys is considered, it becomes imperative to use a more scientific method. However this process is still widely used for heavier classes of work, such as manufacture of anchor chains, while controlled heating furnaces and automatic forging machines have been designed to replace the open-forge fire and the blacksmith's anvil.

13.4.2. Resistance Electric Welding

It is the method of uniting two pieces of metal by the passage of a heavy electric current while the surfaces are pressed together. The fusing temperature is obtained by placing the surfaces to be joined in contact with one another, and passing a current of two to eight volts, at a high amperage through them. The *heat is developed around the point to which they touch, forcing them together* (by pressure mechanically applied), and at the same time *switching off the current, completes the weld.*

The important resistance welding processes are discussed below :

13.4.2.1. Butt welding

Figure 13.1. In this type of welding which is employed to join bars and plates together

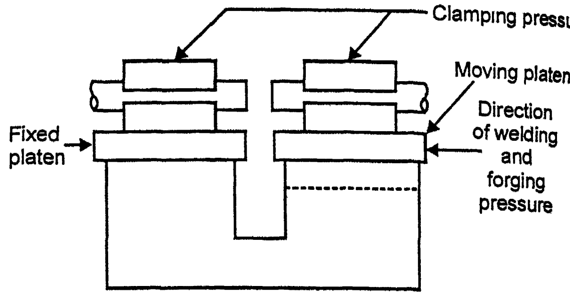


Fig. 13.1. Butt welding.

end-to-end, one bar is held in a fixed clamp in the butt welding machine ; and the other bar in a movable clamp, the clamp being electrically insulated, the one from the other, and being connected to a source of current. When the two ends to be joined are brought into contact and current is switched on, the resistance at the joint causes the ends to heat up to welding temperature. Current is then switched off and the movable clamp forced up, so that a weld is made. The voltage applied across the clamps is a low one, from 2 to 6 volts, and the current is usually alternating. If the bars being joined are different in cross-section the amounts they project from their clamps may have to be adjusted so as to modify the heat losses and ensure both bars being brought to the welding temperature simultaneously.

This process is being used for welding such things as steel rails whose cross-sectional area is as much as 6.25 cm^2.

13.4.2.2. Flash welding

In this process, the parts to welded are clamped to the electrode fixtures, as in butt welding *but the voltage is applied before the parts are butted together.* As the *parts touch each other, an arc is established which continues as long as the parts advance at the correct speed.* This arc bursts away a portion of the material from each piece. When the welding temperature is reached, the speed of travel is increased, the power switched off and weld is upset.

Flash butt welding claims the following *advantages* over upset method of welding : (*i*) Power consumed is less once the arc creates more heat with a given current; (*ii*) The weld is made in clean virgin metal as the surfaces are burned away; (*iii*) More quicker.

It is widely used in automobile construction on the body, axles, wheels, frames and other parts. It is also employed in welding motor frames, transformer tanks and many types of sheet steel containers such as at barrels and floats.

13.4.2.3. Spot welding

Steel, brass, copper and light alloys can be joined by this method, which forms a cheap and satisfactory substitute for riveting. The area of fusion at each spot weld, in fact, is approximately equal to the cross-sectional area of the rivet which would be employed for a similar gauge of material.

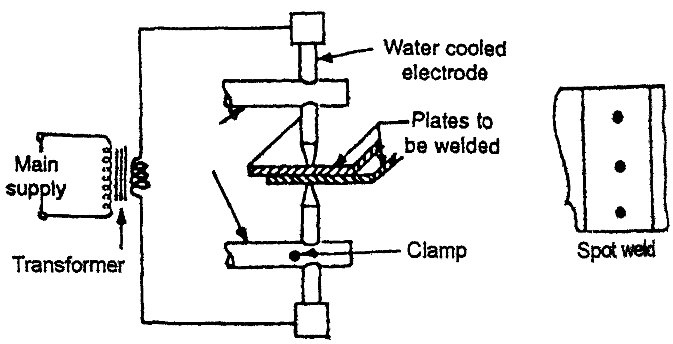


Fig. 13.2. Spot welding.

Refer to Fig. 13.2. Spot

welding, as the name implies, is carried out by overlapping the edges of two sheets of metal and fusing them together between copper electrode tips at suitably spaced intervals by means of a heavy electrical current. The resistance offered to the current as it passes through the metal raises the temperature of the metal between the electrodes to welding heat. The current is cut off and mechanical pressure is then applied by the electrodes to forge the welds Finally the electrodes open.

When sheets of unequal thickness are joined, the current and pressure setting for the thinner sheets are used. Similarly four thickness may be welded, using the same settings as for two thickness.

13.4.2.4. Seam welding

Refer to Fig. 13.3. Seam welding is analogous to spot welding with the difference the electrodes are in the form of rollers; and the *work moves in direction perpendicular to roller axis.* The current is interrupted 300 to 1500 times a minute to give a series of overlapping spot welds. The welding is usually done under water to keep the heating of the welding rollers and the work to a minimum, and thus to give lower roller maintenance and less distortion of the work.

It is employed on many types of pressure (light or leak proof) tanks, for oil switches, transformers, refrigerators, evaporators and condensers, aircraft tanks, paint and varnish containers etc.

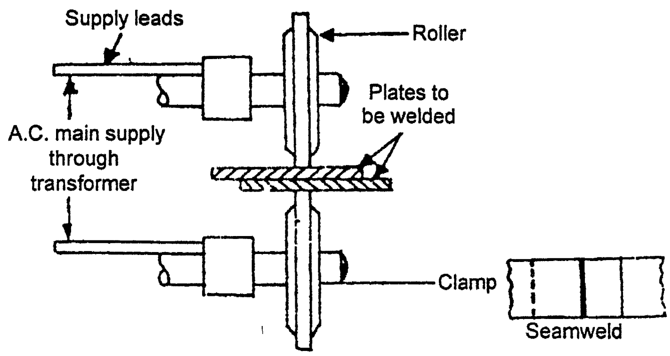


Fig. 13.3. Seam welding.

13.4.2.5. Projection welding

Refer to Fig. 13.4. It is in effect, a form of multi-spot welding in which a number of welds are made simultaneously. The pieces to be welded are arranged between two flat electrodes which exert pressure as the current flows. The projections, and the areas with which they make contact, are raised to welding heat and are joined by the pressure exerted by the electrodes. The projections are flattened during the welding.

The process is used chiefly to join pressings together since it is relatively simple to make the press-tools so that the projections are produced during the main forming operation in the press.

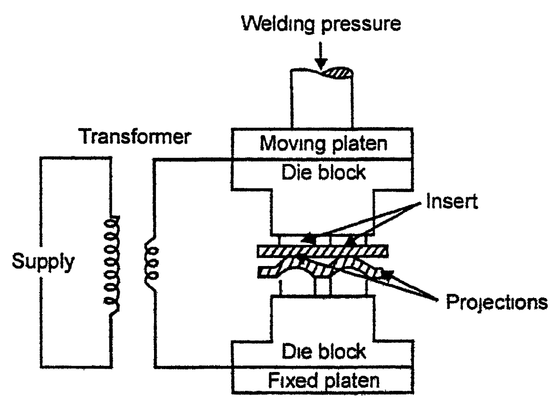


Fig. 13.4. Projection welding.

The same principle is used in the cross welding of a number of wires or rods to make a mesh.

The materials like brass and aluminium cannot be projection welded satisfactorily.

13.5. FUSION WELDING

The characteristic of a fusion weld is that the metal being joined *is actually melted* and the union is produced on subsequent solidification. The group includes :

1. Gas welding; 2. Electric arc welding; 3. Thermit welding.

13.5.1. Gas Welding

- It is a method of fusion welding in which a flame produced by the combustion of gases is employed to melt the metal. The use of an oxyacetylene flame is the most widely employed method of *welding iron, steel, aluminium, cast iron and copper*, the equipment required, as illustrated in Fig. 13.5 being *considerably cheaper and simpler than that needed for electric welding.* For a certain classes of mass production work, however, electric welding will always prove superior both in quickness and cheapness.

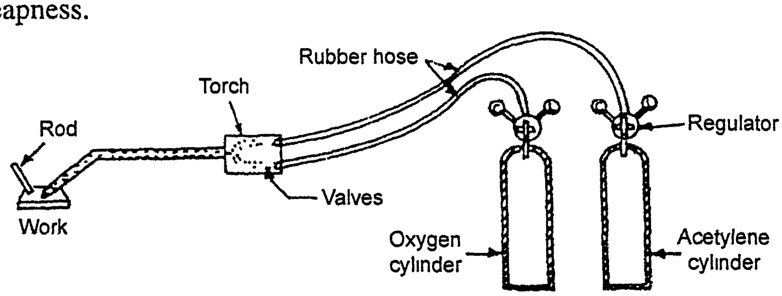


Fig. 13.5.

- The principle of acetylene welding is the ignition of oxygen and acetylene gases, mixed in a blow pipe fitted with a nozzle of suitable diameter ; this flame is applied to the edges of the joint and to a wire filler of the appropriate metal, which is thereby melted and run into the joint. When the acetylene is burned in an atmosphere of oxygen an intensely hot flame with a temperature of about 3300°C is produced. As the melting point of steel is approximately 1300°C, the metal is fused very rapidly at the point at which the flame is applied.
- There are two methods of welding by means of the oxyacetylene blow pipe :
  (*i*) Leftward or forward welding.
  (*ii*) Rightward or backward or backhand welding.
  — In *leftward or forward welding* after suitable preparation of the joint the weld is commenced at the right-hand side of the joint and blow pipe is given a steady

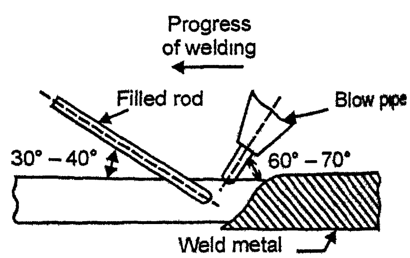


Fig. 13.6. Leftward welding.

forward movement, with a slight sideways motion, zigzagging along the weld towards the left as shown in Fig. 13.6. The blow pipe is kept at an angle of 60° to 70° to the surface of the work so that the flame plays ahead of it, and the filler rod held at an angle of 30° to 40°, is held just ahead of the flame and progressively fed into it. The leftward technique is most suitable for thin material (up to about 0.5 cm) and for all non-ferrous metals.

In *rightward welding* the flame is directed towards the completed part of the joint and welding proceeds from left to right as shown in Fig. 13.7. The filler rod is given a circular movement as it is fed into the flame. The rightward technique is used *for thicker materials, chiefly steel. It uses less gas and filler rod and causes less distortion than leftward welding.*

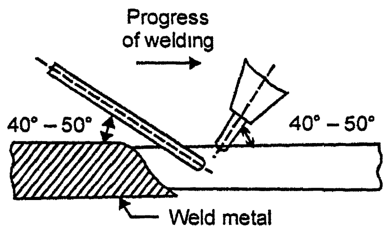


Fig. 13.7. Rightward welding.

Types of flames :

Following are the *three types of flames of oxygen and acetylene mixture :*

1. Neutral flame
2. Carburising flame
3. Oxidising flame.

The brief description of these flames is given below :

1. *Neutral flame.* Refer to Fig. 13.8.

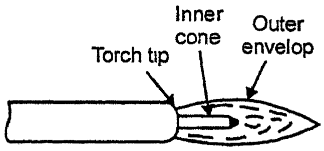


Fig. 13.8. Neutral flame.

- When the *ratio of oxygen and acetylene is equal,* a neutral flame is obtained.
- This type of flame has a temperature of 3250°C, is white in colour and has a sharply defined central cone with a reddish purple envelope.
- It does not react chemically with the parent metal and protects it (the metal) from oxidation.
- The neutral flame is used to weld carbon steels, cast iron, copper, aluminium etc.

2. *Carburising flame.* Refer to Fig. 13.9.

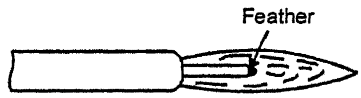


Fig. 13.9. Carburising flame (Excess acetylene).

- *The ratio of oxygen to acetylene is 0.9 to 1.* It consists of the following three zones :
  — Luminous zone,
  — Feather or intermediate cone of white colour, and
  — Outer envelope.
- It is also called as *reducing flame* and has a temperature of 3040°C.
- *The carburising flame is used* for the following purposes :
  To join those materials which are *readily oxidised.* Thus it is used to weld aluminium since it prevents the formation of aluminium oxide at the time of welding.

— To weld monel metal, high carbon steel and alloy steel.
— To give a hard facing material in some cases.

3. ***Oxidising flame.*** Refer to Fig. 13.10.

- The *ratio of oxygen to acetylene varies from about 1.2 to 1.5.*
- It is used in the following cases :
  — To weld copper, brass and bronze and zinc-bearing alloys.
  — For gas cutting.

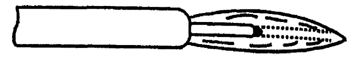


Fig. 13.10. Oxidising flame (Excess oxygen).

It may be noted that although, in gas welding, oxygen and acetylene mixture is popular, other fuel gases like propane, hydrogen and coal gas may also be used along oxygen to produce gas flames for welding.

Equipment :

For gas welding following equipments are used :

1. Gas cylinders
2. Pressure regulators
3. Pressure gauges
4. Welding torch
5. Hoses and hose fittings
6. Safety devices etc.

The brief description of the above equipments is given below :

1. Gas cylinders :

A. *Oxygen cylinder :*

— For safety purposes oxygen cylinders are filled at a pressure 12500 to 14000 kN/m^2 and cylinder capacity is 6.23 m^3.
— The cylinder is provided with a right *hand thread valve* and is painted *black.*
— The cylinders are usually provided with fragile disc and fusible plug to relieve the cylinder of its contents if subjected to overheating or excessive pressure.

B. *Acetylene cylinder :*

— The cylinder is usually filled to pressure of 1600 to 2100 kN/m^2.
— The cylinder is provided with *left hand threads* for accommodating pressure regulator and is painted *maroon.*
— Acetylene gas above one atmospheric pressure is highly explosive. Hence acetylene is stored with calcium silicate saturated with acetone. Acetone can absorb 25 times its own volume of acetylene for each atmospheric pressure.

2. Pressure regulators. The cylinders are provided with pressure regulators to control the working pressure of oxygen and acetylene to the welding torch. The pressure of oxygen and acetylene depends on the thickness of the metal to be welded/cut.

3. Pressure gauges. Two pressure gauges are fitted on each pressure regulator. While one pressure gauge shows the pressure inside the cylinder, the other one shows the working pressure of the fuel gas and oxygen.

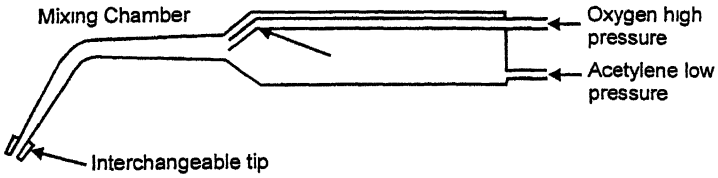


Fig. 13.11. Low pressure blow pipe.

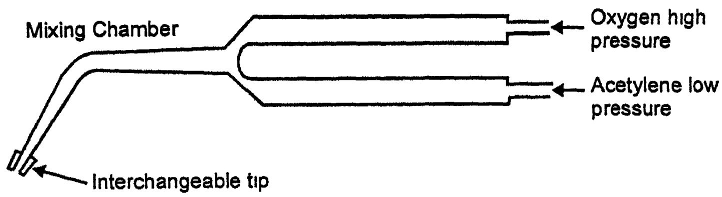


Fig. 13.12. High pressure blow pipe.

4. Welding torch/blow pipe. It is a device; for mixing oxygen and acetylene in the required volume and igniting it at the mouth of its tip. Generally following two types of torches are available :

(1) Low pressure blow pipe (Injector type).

(2) High pressure blow pipe.

5. Hose and hose fittings :

- Hoses are the rubber and fabric pipes used to connect gas cylinder to blow pipe and are painted black or green for oxygen and red or maroon for acetylene. It should be strong, durable, non-porous and light.
- Special fittings are used for connecting hoses to equipment.

6. Safety devices :

- *Goggles* fitted with coloured glasses should be used to protect the eyes from harmful heat ultraviolet rays.
- *Gloves* made of leather, canvas and asbestos should be worn to protect hands from any injury. Gloves should be light so that the manipulation of the torch may be done easily.

Other requirements include *spark-lighter, apron, trolley, wire brush, spindle key, spanner set, filter rods and fluxes and welding tips.*

Advantages and disadvantages of gas welding :

Advantages :

1. The oxy-acetylene torch is *versatile.* It can be used for brazing, bronze welding, soldering, heating, heat treatment, metal cutting, metal cleaning etc.
2. It is portable and can be moved almost everywhere for repair of fabrication work.
3. The oxy-acetylene flame is easily controlled and not as piercing as metallic arc welding, hence, extensively used for sheet metal fabrication work.
4. Welder has considerable control over the temperature of the metal in the weld zone.

When the rate of heat input from the flame is properly coordinated with the speed of welding, the size, viscosity and surface tension of the weld puddle can be controlled, *permitting the pressure of the flame to be used to aid in positioning and shaping the weld.*

5. The cost and maintenance of the gas welding equipment is low when compared to that of some other welding processes.
6. The rate of heating and cooling is relatively low. In some cases, this is an advantage.

Disadvantages :

1. As compared to arc welding, it takes considerably longer time for the metal to heat up.
2. Owing to prolonged heating harmful thermal effects are aggravated which results in a larger heat affected area, increased grain growth, distortion and less of corrosion resistance.
3. Oxygen and acetylene gases are expensive.
4. Flux applications and the shielding provided by the oxy-acetylene flame are not so positive as those supplied by the inert gas in TIG, MIG or CO_2 welding.
5. The handling and storing of gas necessitate lot of safety precautions.
6. Heavy sections cannot be joined economically.
7. Flame temperature is less than the temperature of the arc.

TABLE 13.1

Comparison between A.C. and D.C. arc Welding

The comparison between A.C. and D.C. arc welding is given in the table below :

S.No.	*Aspects*	*A.C. welding*	*D.C. welding*
1.	*Power consumption*	Low	High
2.	*Arc stability*	Arc unstable	Arc stable
3.	*Cost*	Less	More
4.	*Weight*	Light	Heavy
5.	*Efficiency*	High	Low
6.	*Operation*	Noiseless	Noisy
7.	*Suitability*	Non-ferrous metals cannot be joined	Suitable for both ferrous and non-ferrous metals
8.	*Electrode used*	Only coated	Bare electrodes are also used
9.	*Welding of thin sections*	Not preferred	Preferred
10.	*Miscellaneous*	Work can act as cathode while electrode acts as anode and *vice versa*	Electrode is always negative and the work is positive

Specifications :

A.C. transformer : Step down, oil cooled = 3 phase, 50 Hz ; Current range = 50 to 400 A; Open circuit voltage = 50 to 90 V ; Energy consumption = 4 kWh per kg of metal deposit; Power factor = 0.4 ; Efficiency = 85%.

D.C. generator : Motor generator—3 phase, 50 Hz; Current range = 125 to 600 A; Open circuit voltage = 30 to 80 V; Arc voltage = 20 to 40 V; Energy consumption = 6 to 10 kWh/kg of deposit; Power factor = 0.4 ; Efficiency = 60%.

Electrodes :

The electrodes may be of the following two types :

1. *Consumable electrode :*

(*i*) Bare electrode

(*ii*) Flux coated electrode.

2. *Non-consumable electrode :*

1. *Consumable electrode :*

(*i*) *Bare electrode :*

- These electrodes do not prevent oxidation of the weld and hence the joint is weak. They are used for minor repairs where strength of the joint is weak.
- Employed in automatic and semi-automatic welding.

(*ii*) *Flux coated electrode :*

- The flux is provided to serve the following purposes :
  — To prevent oxidation of the weld bead by creating a gaseous shield around the arc.
  — To make the formation of the slag easy.
  — To facilitate the stability of the arc.

2. *Non-consumable electrode :*

- These electrodes are 12 mm in diameter and 450 mm long.
- These are not consumed during the welding process.

Examples of these electrodes are : *Carbon, graphite and tungsten.*

Types of welded joints :

The type of joint is determined by the relative positions of the two pieces being joined. The following are the five basic types of commonly used joints :

1. Lap joint
2. Butt joint
3. Corner joint
4. Edge joint
5. T-joint.

1. *Lap Joint.* Refer to Fig. 13.13.

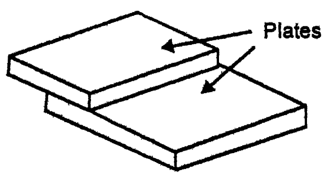


Fig. 13.13. Lap joint.

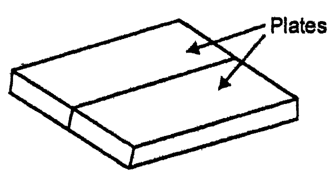


Fig. 13.14. Butt joint.

- The lap joint is obtained by overlapping the plates and then welding the edges of the plates.

- The lap joints may be *single traverse, double traverse and parallel* lap joints.
- These joints are employed on plates having thickness *less than 3 mm.*

2. ***Butt joint :***
- The butt joint is obtained by placing the plates edge to edge as shown in Fig. 13.14.
- In this type of joints, if the plate thickness is *less than 5 mm*, bevelling is *not* required. When the thickness of the plates ranges *between 5 mm to 12.5 mm*, the edge is required to be bevelled to V or U-groove, while the plates having thickness *above 12.5 mm* should have a V or U-groove on both sides.
- The various types of butt joints are shown in Fig. 13.15.

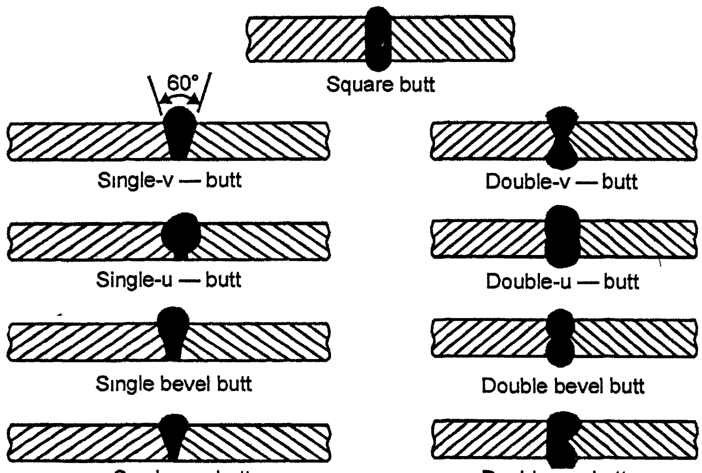


Fig. 13.15. Various types of butt joints.

3. *Corner joint.* Refer to Fig. 13.16.
- A corner joint is obtained by joining the edges of two plates whose surfaces are at an angle of 90° to each other.
- In some cases corner joint can be welded, without any filler metal, by melting off the edges of the parent metal.
- This joint is *used for both light and heavy gauge sheet metal.*

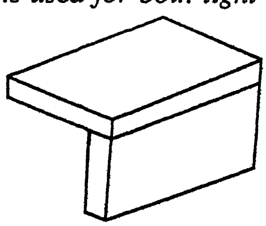


Fig. 13.16. Corner joint.

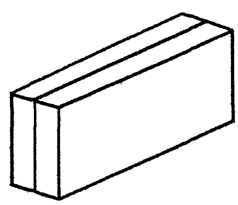


Fig. 13.17. Edge joint.

4. *Edge Joint.* Refer to Fig. 13.17.
- This joint is obtained by joining two parallel plates.
- It is *economical for plates having thickness less than 6 mm.*
- It is *unsuitable for members subjected to direct tension or bending.*

5. ***T-joint.*** Refer to Fig. 13.18.

- It is obtained by joining two plates whose surfaces are approximately at right angles to each other.
- These joints are suitable up to 3 mm thickness.
- T-joint is widely *used to weld siffeners in air craft and other thin walled structures.*

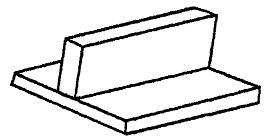


Fig. 13.18. T-joint.

Note. The lap joints, corner joints and T-joints are known as **fillet weld joints.** The fillet cross-section is approximately triangular. Fig. 13.19 shows the three types of fillet welds.

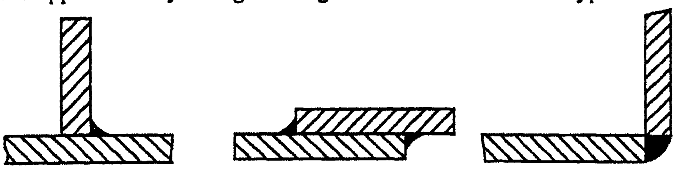


Fig. 13.19.

Welding positions :

It is easiest to make welds in *flat positions, i.e.,* both the parent metal pieces lying in horizontal plane over a flat surface. But, several times it becomes unavoidable to weld the workpieces in some other positions also. The common welding positions are :

1. Flat position
2. Horizontal position
3. Vertical position
4. Overhead position.

1. ***Flat position.*** Refer to Fig. 13.20.

- In this welding position, the welding is done from the upper side of the joint and the welding material is normally applied in the downward direction.
- On account of the downward direction of application of welding material this position is also sometimes called as *downward position.*

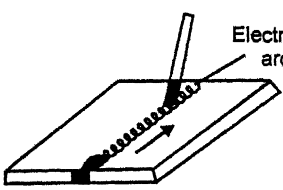


Fig. 13.20. Flat position.

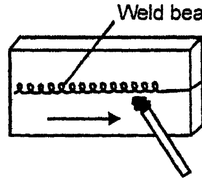


Fig. 13.21. Horizontal position.

2. ***Horizontal position.*** Refer to Fig. 13.21.

In this case, the weld is deposited upon the side of a horizontal and against a vertical surface.

3. ***Vertical position.*** Refer to Fig. 13.22.

- In this position, the axis of the weld remains either vertical or at an inclination of less than 45° with the vertical plane.
- The welding commences at the bottom and proceeds upwards.

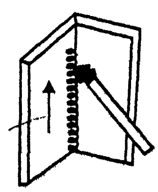


Fig. 13.22. Vertical position.

- The tip of the torch is kept pointing upwards so that the pressure of the outcoming gas mixture forces the molten metal towards the base metal and prevents it from falling down.

4. ***Overhead position.*** Refer to Fig. 13.23.
   - In this case, the welding is performed from the underside of the joint. The workpieces remain over the head of the welder.
   - The workpieces as well as axis of the weld all remain in approximately horizontal plane.
   - It is reverse of flat welding.

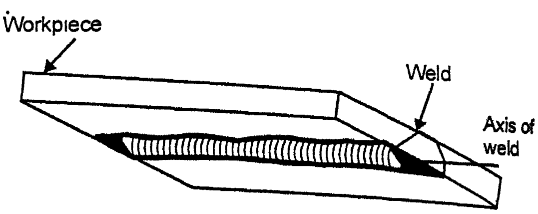


Fig. 13.23. Overhead position.

13.5.2. Electric Arc Welding

Arc welding is the system in which the metal is melted by the heat of an electric arc. It can be done with the following methods :

(*i*) Metallic arc welding.
(*ii*) Carbon arc welding.
(*iii*) Atomic hydrogen welding.
(*iv*) Shielded arc welding.

13.5.2.1. Metallic arc welding

Refer to Fig. 13.24. In metallic arc welding an arc is established between work and the filler metal electrode. The intense heat of the arc forms a molten pool in the metal being welded, and at the same time melts the tip of the electrode. As the arc is maintained, molten filler metal from the electrode tip is transferred across the arc, where it fuses with the molten base metal.

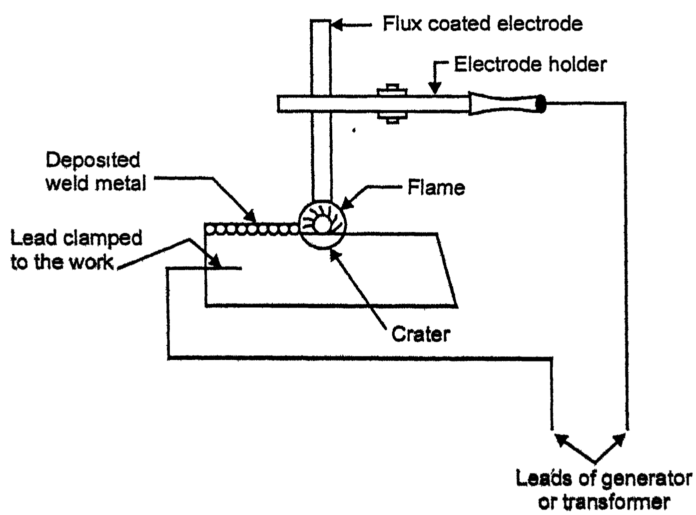


Fig. 13.24. Metallic arc welding.

Arc may be formed with direct or alternating current. Petrol or diesel driven generators are

widely used for welding in open, where a normal electricity supply may not be available. D.C. may also be obtained from electricity mains through the instrumentality of a transformer and rectifier. A simple transformer is, however widely employed for A.C. arc welding. *The transformer sets are cheaper and simple having no maintenance cost as there are no moving parts.* With Arc system, the covered or coated electrodes are used, whereas with D.C. system for cast iron and non-ferrous metals, bare electrodes can be used. In order to strike the arc an open circuit voltage of between 60 to 70 volts is required. For maintaining the short arc 17 to 25 volts are necessary; the current required for welding, however, varies from 10 amp. to 500 amp. depending upon the class of work to be welded.

The great *disadvantage* entailed by D.C. welding is the presence of *arc blow* (distortion of arc stream from the intended path owing to magnetic forces of a non-uniform magnetic field). With A.C. arc blow is considerably reduced and use of higher currents and large electrodes may be restored to enhance the rate of weld production.

The field of application of metallic arc welding includes mainly low carbon steel and the high-alloy austenitic stainless steel. Other steels like low and medium-alloy steels can however be welded by this system but many precautions need be taken to produce ductile joints.

13.5.2.2. Carbon arc welding

Refer to Fig. 13.25. Here the work is connected to negative and the carbon rod or electrode connected to the positive of the electric circuit. Arc is formed in the gap, filling metal is supplied by fusing a rod or wire into the arc by allowing the current to jump over it and it produces a porous and brittle weld because of inclusion of carbon particles in the molten metal. It is therefore *used for filling blow holes in the castings which are not subjected to any of the stresses.*

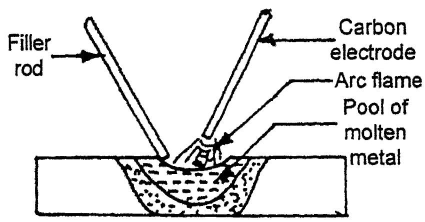


Fig. 13.25. Carbon arc welding.

The voltage required for striking an arc with carbon electrodes is about 30 volts (A.C.) and 40 volts (D.C.).

A *disadvantage* of carbon arc welding is that approximately twice the current is required to raise the work to welding temperature as compared with a metal electrode, while a carbon electrode can only be used economically on D.C. supply.

13.5.2.3. Atomic hydrogen welding

Refer to Fig. 13.26. In this system heat is obtained from an alternating current arc drawn between two *tungsten electrodes in an atmosphere of hydrogen.* As the hydrogen gas passes through the arc, the hydrogen molecules are broken up into atoms and they recombine on contact with the cooler base metal generating intense heat sufficient to melt the surfaces to be welded, together with the filler rod, if used. The envelop of hydrogen gas also shields the molten metal from oxygen and nitrogen and thus prevents weld metal from deterioration.

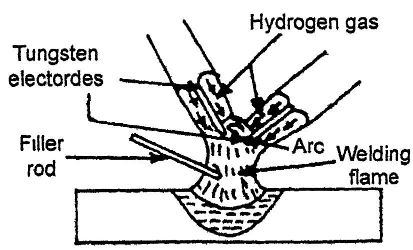


Fig. 13.26. Atomic hydrogen welding.

The welds obtained are homogeneous and smooth in appearance because the hydrogen keeps the molten pool. *Atomic hydrogen welding being expensive is used mainly for high grade work on stainless steel and most non-ferrous metals.*

13.5.2.4. Shielded arc welding

In this system molten weld metal is protected from the action of atmosphere by an envelope of chemically reducing or inert gas.

As molten steel has an affinity for oxygen and nitrogen, it will, if exposed to the atmosphere, enter into combination with these gases forming oxides and nitrides. Due to this injurious chemical combination metal becomes weak, brittle and corrosion resistant. Thus several methods of shielding have been developed. The simplest (Fig. 13.27) is the use of a flux coating on the electrode which in addition to producing a slag which floats on the top of the molten metal and protects it from atmosphere, has organic constituents which turn away and produce an envelope of inert gas around the arc and the weld. Welds made with a completely shielded arc are more superior to those deposited by an ordinary arc.

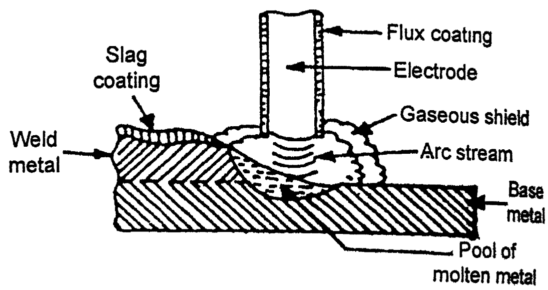


Fig. 13.27. Shielded arc welding.

13.5.3. Thermit Welding

Refer to Fig. 13.28. *It is the method of uniting iron or steel parts by surrounding the joint with steel at a sufficient high temperature to fuse the adjacent surfaces of the parts together.* Here a wax pattern of desired size and shape is prepared around the joint or region where the weld is to be affected. The wax pattern is then. surrounded by sheet iron box and the space between box and pattern is filled and rammed with *sand.* After cutting, pouring and heating gates and risers a flame is directed into the heating oven due to which the wax pattern melts and drains out, the heating is continued to raise the temperature of the parts to be welded. The thermit mixture (finely divided aluminium iron oxide) is packed in the crucible of conical shape formed from a sheet-iron casting lined with heat resisting cement and is ignited with magnesium or torch yielding a highly superheated (nearly 3000°C) molten-iron and a slag of aluminium oxide.

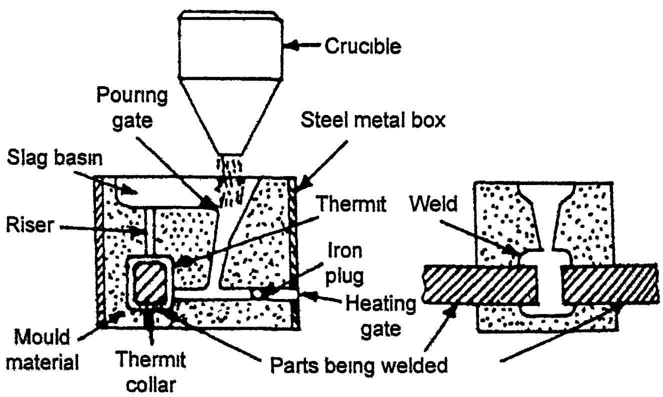


Fig. 13.28. Thermit welding.

The molten iron is then run into the mould which fuses with the parts to be welded and forms a thermit collar at the joint. The welds thus obtained are metallurgically very sound and strong.

The process is widely employed in the *shipping, steel and railroad industries.* It can also be used for welding non-ferrous parts by selection of a mixture of oxides which on reduction with aluminium will provide an alloy approximating the material to be welded.

13.6. MODERN WELDING TECHNIQUES

13.6.1. Tungsten Inert-Gas (TIG) Welding

Refer to Fig. 13.29. In this process the heat necessary to melt the metal is provided by a very intense electric arc which is struck between a virtually *non-consumable tungsten electrode and metal work piece. The electrode does not melt* and become a part of the weld. On joints where filler metal is required, a welding rod is fed into the weld zone and melted with base metal in the same manner as that used with oxyacetylene welding. The weld zone is shielded from the atmosphere by an inert-gas (a gas which does not combine chemically with the metal being welded) which is ducted directly to the weld zone where it surrounds the tungsten. The major inert gases that are used are *argon* and *helium.*

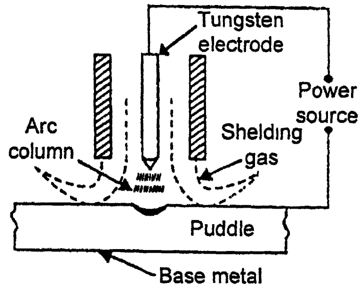


Fig. 13.29. Tungsten inert-gas (TIG) welding.

TIG process offers the following *advantages :*

(1) TIG welds are stronger, more ductile and more corrosion resistant than welds made with ordinary shield arc welding.

(2) Since no granular flux is required, it is possible to use a wide variety of joint designs than in conventional shield arc welding or stick electrode welding.

(3) There is little weld metal splatter or weld sparks that damage the surface of the base metal as in traditional shield arc welding.

Uses of TIG welding :

(*i*) The TIG process lends itself ably to the fusion welding of *aluminium and its alloys, stainless steel, magnesium alloys, nickel base alloys, copper base alloys, carbon steel and low alloy steels.*

(*ii*) TIG welding can also be used for the combining of dissimilar metals, hard facing, and the surfacing of metals.

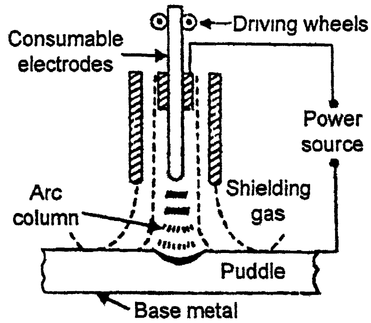


Fig. 13.30. Metal inert-gas welding (MIG).

13.6.2. Metal Inert-Gas (MIG) Welding

Refer to Fig. 13.30. The inert-gas *consumable electrode process,* or the MIG process is a refinement of the TIG process, however, in this process, the *tungsten electrode has been replaced with a consumable electrode.* The electrode is driven

through the same type of collet that holds a tungsten electrode by a set of drive wheels. The *consumable electrode in MIG process acts as the source for the arc column as well as the supply for the filler material.*

MIG welding employs the following *three basic processes.*

1. Bare-wire electrode process.
2. Magnetic flux process.
3. Flux-cored electrode process.

Uses of MIG welding :

(*i*) Practically all commercially available metals can be welded by this method.

(*ii*) It can be used for deep groove welding of plates and castings, just as the submerged arc process can, but it is more advantageous on light gauge metals where high speeds are possible.

Difference between TIG and MIG welding processes :

S.No.	*Aspects*	*TIG welding*	*MIG welding*
1.	*Name of the process*	Tungsten inert-gas welding.	Metal inert-gas welding.
2.	*Type of electrode used*	Non-consumable tungsten electrode.	Consumable metallic electrode.
3.	*Electrode Feed*	Electrode feed not required.	Electrode need to be fed at a constant speed from a wire reel.
4.	*Electrode holder*	It is called welding torch and has got a cap filled on the back to cover the tungsen electrode. It has also got connections for shielding gas, cooling water and control cable. It may be air-cooled also.	It is called welding gun or torch. It has facility to continuously feed wire electrode; shielding inert-gas, cooling water and control table.
5.	*Welding current*	Both A.C. and D.C. can be used.	D.C. with reverse polarity is used.
6.	*Feed metal*	Filler metal may or may not be used.	Filler metal in the form of fire wire is used.
7.	*Bases metal thickness*	Metal thickness which can be welded is limited to about 5 mm.	Thickness limited to about 40 mm.
8.	*Welding speed*	Slow.	Fast.

13.6.3. Submerged Arc Welding

The *submerged arc process* (which may be done manually or automatically) *creates an arc column between a base metallic electrode and the workpiece.* The arc, the end of the electrode, and the molten weld pool are *submerged in a finely divided granulated powder that contains appropriate deoxidizers, cleansers and any other fluxing elements.* The fluxing powder is fed from a hopper that is carried on the welding head. The tube from the hopper spreads the powder

in continuous mount in front of the electrode along the line of the weld. This *flux mound is of sufficient depth to submerge completely the arc column so that there is no splatter or smoke*, and the weld is shielded from all effects at atmospheric gases. As a *result of this unique protection, the weld beads are exceptically smooth.* The flux adjacent to the arc column melts and floats to the surface of the molten pool ; then it solidifies to form a slag on the top of the welded metal. The rest of the flux is simply an insulator that can be reclaimed easily. The slag that is formed by the molten flux solidifies and is easy to remove. In fact, in many applications, the slag will crack off by itself as it cools. The unused flux is removed and placed back into the original hopper for use for the next time. Granulated flux is a complex, metallic for silicate that can be used over a wide range of metals.

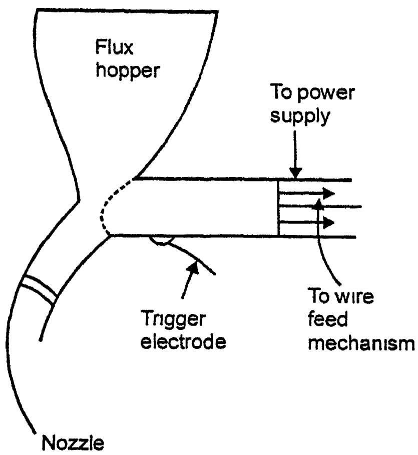


Fig. 13.31. Apparatus used in manual submerged are welding.

The process is characterised by high welding currents. The current density in the electrode is 5 to 6 times that used in ordinary manual stick electrode arc welding, consequently the melting rate of the electrode as well as the speed of welding is much higher than in the manual stick electrode process.

Figure 13.31 shows an apparatus used in manual submerged arc welding.

Welds made by the submerged arc welding process have high strength and ductility with low hydrogen or nitrogen content.

This process is suitable for welding low-alloy, high tensile steels as well as the mild, low-carbon steels. This process is also capable of joining medium carbon steels, heat resistant steels, and many of the high-strength steels. Also the process is adaptable to nickel, monel and many other non-ferrous metals.

The submerged arc process is also capable of welding fairly thin gauge materials.

13.6.4. Electro-Slag and Electro-Gas Welding

These methods are employed to *fuse two sections of thick metal,* forming a seam in a *single pass.* Elimination of the need for making multiple passes and special joint preparations make these methods commonly used welding processes when heavy ferrous metals are to be joined. These processes have reduced costly time in fabrication of *large vessels and tanks.*

There is theoretically no limit to the thickness of the weld bead.

13.6.4.1. Electro-slag welding

Refer to Fig. 13.32. This process is a vertical and uphill, two copper shoes, dams, or moulds must be placed on either side of the joint that is to be welded in order to keep the molten metal in the joint area. One or more electrodes may be used to weld a joint, depending upon the thickness of the metal. The electrodes are fed into the weld joint almost vertically from special wire guides. Electrodes need not be of a special deoxidized nature but they may contain a flux,

if it is needed. A mechanism for raising the equipment as the weld is completed and A.C. power source that has approximately 100 amperes output and a 100 per cent duty cycle are needed. *Electro-slag welding depends upon the generation of heat that is produced by passing an electric current through molten slag.*

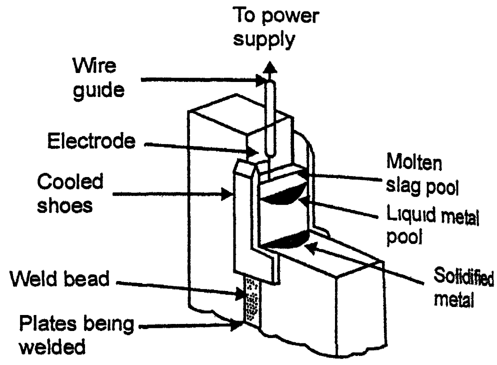


Fig. 13.32. Electro-slag welding.

13.6.4.4. Electro-gas welding

Refer to Fig. 13.33. Electro-gas welding works on the same general principle as electro-slag welding, with *the addition of some of the principles of submerged arc welding.* The major difference between electro-slag and electro-gas welding is that an inert gas, such as CO_2, is used to shield the weld from oxidation, and there is continuous arc, such as in submerged arc welding, to heat the weld pool. The joints and the use of flux to cleanse the weld are the same

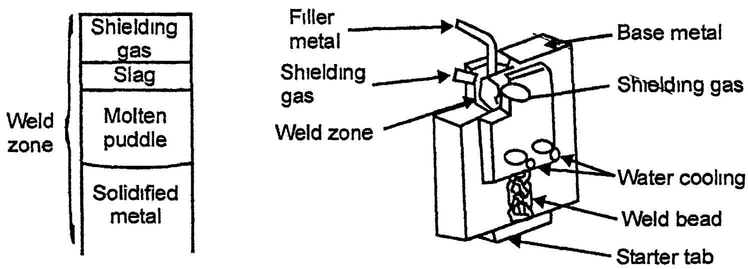


Fig. 13.33. Electro-gas welding.

as in electro-slag process. The shoes that are used to form the weld, as in electro-slag process, are also used in the electro-gas process to control the weld zone through water cooling. However, the flux, instead of being issued to the weld zone through a hopper mechanism, is incorporated within the electrode itself in the form of cored wires.

13.6.5. Electron-Beam Welding

Electron-beam welding fusion joins metal by bombarding a specific confined area of the base metal with high velocity electrons. The operation is performed in a vacuum to prevent the reduction of electron velocity. If a vacuum were not used, the electrons would strike the small particles in the atmosphere, reducing their velocity and decreasing their heading ability. The electron beam welding process allows fusion welds of great depth with a minimum width because the beam can be focused and magnified (Fig. 13.34). The depth of the weld bead can exceed the width of the weld bead by as much as 15 times. The *process joins separate pieces of base metal by fusing of molten metals. The melting is achieved by a concentrated bombardment of a dense stream of electrons, which are accelerated at high velocities,* sometimes as high as the speed of light. Under most circumstances the entire process is done inside a vacuum chamber.

Most chambers house not only the workpiece but also the cathode, the focusing device and the remainder of the gun, preventing contamination of the weldment and the electron-beam gun itself (Fig. 13.35).

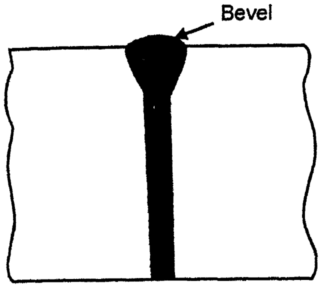


Fig. 13.34. Electro-beam welding.

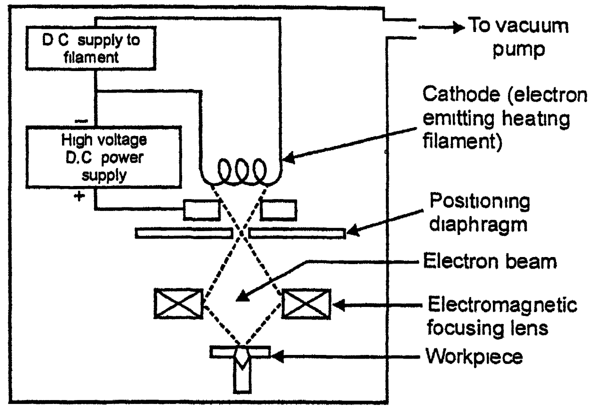


Fig. 13.35. Electron-beam gun.

Advantages :

(*i*) The greatest advantage of electron-beam welding is that *it eliminates contamination of both the weld zone and the weld head* because of the vacuum in which the weld is done because of the electrons doing the heating.

(*ii*) Even though initial costs are high, *operating costs are low* due to the low power usage. Many of the more costly fabrication methods could be replaced by electron beam process.

(*iii*) The narrow beam *reduces the distortion of the workpiece, making the replacement of costly jigs and fixtures less necessary* than when using other types of welding processes.

13.6.6. Ultrasonic Welding

A schematic diagram of a typical ultrasonic welding is shown in Fig. 13.36. The welding equipment consists of two units :

(*i*) *A power source of frequency converter which converts 50 cycle line power into high frequency electric power.*

(*ii*) *A transducer which changes the high frequency electric power into vibratory energy.*

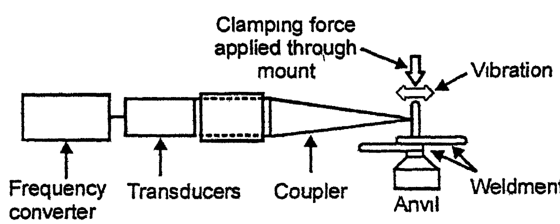


Fig. 13.36. Ultrasonic welding.

The components to be joined are simply clamped between a welding tip and supporting anvil with just enough pressure to hold them

in close contact. The high frequency vibratory energy is then transmitted to the joint for the required period of time. The bonding is accomplished without applying external heat, filler rod or melting metal. Either spot-type welds or continuous-seam welds can be made on a variety of metals ranging of thickness from 0.000425 mm (aluminium foil) to 0.25 mm. Thicker sheet and plate can be welded if the machine is specifically designed for them. High strength bonds are possible both in similar and dissimilar metal combinations.

Uses. Ultrasonic welding is particularly adaptable for :

(1) Joining electrical and electronic components.

(2) Thermetic sealing of materials and devices.

(3) Splicing metallic foil.

(4) Welding aluminium wire and sheet.

(5) Fabricating nuclear fuel elements.

13.6.7. Plasma Arc Welding

- *Plasma* is often considered the *fourth state of matter.* The other three are gas, liquid and solid. Plasma results when a gas is heated to high temperature and changes into positive ions, neutral atoms and negative electrons. When a matter passes from one state to another latent heat is required to change into steam, and similarly, the plasma torch supplies energy to a gas to change it into plasma. When the *plasma changes back to a gas, the heat is released. Any high current arc is composed of plasma, which is nothing more than an ionized conducting gas.* The plasma gas is forced through the torch, surrounding the cathode. The main function of the plasma gas is shielding the body of the torch from the extreme heat of the cathode. Argon and argon mixtures are most commonly used (since they do not attack tungsten or copper cathode).
- *Plasma arc consists of an electronic arc plasma gas, and gases used to shield the jet column. The equipment necessary for plasma arc welding includes a conventional D.C. power supply with a drooping volt ampere output and with 70 open line volts.*
- The two main types of torches for welding and cutting with plasma arc are :
  (*i*) Transferred arc, and
  (*ii*) Non-transferred arc.
- The ***'transferred arc'*** plasma jet torch (Fig. 13.37) is similar to

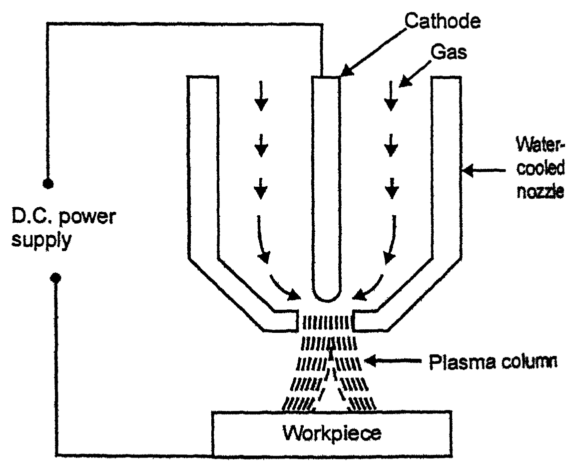


Fig. 13.37. Transferred arc plasma jet torch.

TIG torch, except that it has the water-cooled nozzle between the electrode and the work. This nozzle constricts the arc, increasing its pressure.

The plasma, caused by the collision of gas molecules with high-energy electron, is then swept out through the nozzle, forming the main current path between the electrode and the work-piece. *The plasma arc and transferred arc are generated between the tungsten electrode or cathode and the work-piece, or anode.*

- The *'Non-transferred arc'* torch extends the arc from the electrode, or the cathode, to the end of the nozzle. *The nozzle acts as the anode. This type of plasma jet is completely independent of the workpiece, with the power supply contained within the equipment.*

Kay-hole method is used in actual process of welding with plasma jet. Jet column burns a small hole through the materials to be welded. As the torch progresses along the material the hole progresses also. However, it is filled by molten metal as the torch passes. Hundred per cent penetration is ensured by this method.

13.6.8. Laser Beam Welding

- The laser welding process is the *focusing of a monochromatic light into extremely concentrated beams.* It employs a carefully *focused beam of light that concentrates tremendous amount of energy on a small area to produce fusion.*

Refer to Fig. 13.38. The laser welding system comprises the following :

1. Electrical storage unit.
2. Capacitor bank.
3. Triggering device.
4. Flash tube that is wrapped with a wire.
5. Lasing material.
6. Focusing lens mechanism.
7. Work-table (operatable in three axes X, Y and Z).

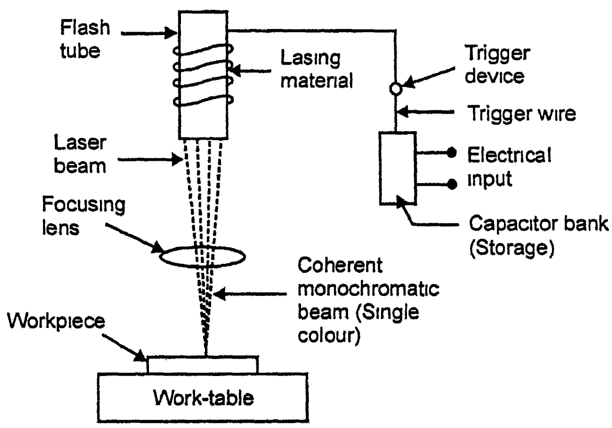


Fig. 13.38. Laser beam welding.

When capacitor bank is triggered energy is injected into the wire that surrounds the flash tube. This wire establishes an imbalance in the material inside the flash tube. Thick xenon often is used in the material for the flash tube, producing high power levels for very short period of time. The flash tubes or lamps are designed for operation at a rate of thousands of flashes per second. By operating in this manner, the lamps become an efficient device for converting *electrical energy into light energy,* the process of pumping the laser. The laser is then activated. The beam is emitted through the coated end of the lasing material. It goes through a focusing device where it is pin-pointed on the workpiece. Fusion takes place and the weld is accomplished.

Advantages :

(*i*) This process can be used to weld *dissimilar metals with widely varying physical properties.*

(*ii*) *Metals with relatively high electrical resistance and parts of considerably different sizes and mass can be welded.*

(*iii*) Because the laser is simply a beam, *no electrode is required,* so that any part in a particular position can be welded if there is a direct line of sight from beam to the workpiece.

(*iv*) Welds can be made with a *high degree of precision* and on material that is only a few thousands of a centimetre thick.

(*v*) Laser welding holds thermal distortion and shrinkage to a minimum.

Disadvantage :

Energy losses are high.

13.6.9. Hydrodynamic Welding

- Hydrodynamic welding technique offers many advantages such as speed, reproducibility of results and an automatic operation and it *requires no weld metal.*
- The process utilises both thermal energy and shock waves discharged through a common weld head. The *two important steps involved are :*

  (*i*) Induction heating;

  (*ii*) Magnetic pulse pressurizing.

After welding the object can be cooled at a controlled rate to produce the desired microstructure in the joint region

- It can be *used to join steel to many ferrous and non-ferrous metals and alloys.*

13.6.10.Cold Welding

- This process utilizes only the pressure to produce the joints at room temperature and *no heat is applied at any stage.*
- The pressure required to cause cold welding is usually large (1380 MN/m^2) and the metal surfaces must be thoroughly cleaned, prefereably by mechanical means and must be free from grease.
- The cold welding process is applicable to non-ferrous metals and alloys such as aluminium, copper, brass, lead, zinc, silver and gold. It is *used for the production of special Al-Cu tubes for refrigerators, in the assembly of transistors and other electrical devices and for the welding of lids of aluminium food containers.*

13.7. ELECTRODES

- Proper choice of electrodes is a vital point in getting good welds. Good preliminary precautions are of no use by improper choice of electrodes.
- The electrodes have two parts. One is *core wire* which contains the metal to be deposited. The second one is *coating. The heat causes the coating to emit gases, which cover the weld and prevent bare metal from oxidation.* Contamination with

water impares the effectiveness of coating and hence the *electrodes must be kept in fairly dry places*. Some electrodes do not have any coating.

- *Hand operated electrodes* are normally "extruded wire" with coating over it. The coating may contain ingredients like SiO_2, TiO_2, FeO, MgO, Al_2O_3 and cellulose in various proportions.

Electrode materials :

Depending upon job material, the following electrode materials are in use :

(*i*) Mild steel
(*ii*) Low alloy steel
(*iii*) Nickel steel
(*iv*) Chrome-moly steel
(*v*) Manganese-moly steel
(*vi*) Nickel manganese-moly steel
(*vii*) Nickel-moly-vanadium steel
(*viii*) Aluminium
(*ix*) Copper-aluminium
(*x*) Lead-bronze
(*xi*) Phosphor bronze.

Electrode coatings :

The electrode coatings are made to serve the following *purposes :*

(*i*) To provide a gaseous shield to prevent atmospheric contamination.
(*ii*) To help stabilise and direct the arc for effective penetration.
(*iii*) To act as scavengers to reduce oxides.
(*iv*) To control surface tension in the pool to influence the shape of the bead formed when the metal freezes.
(*v*) To add alloying elements to the weld.
(*vi*) To insulate the electrode electrically.
(*vii*) To minimise splatter of the weld metal.
(*viii*) To form a plasma to conduct current across the arc.
(*ix*) To form a slag to carry off impurities, protect the hot metal and slow the cooling rate.

Electrodes' designation :

- The *electrodes are designated by numbers which indicate grade and by sizes of the core wire.*
- The sizes are given by absolute sizes (*e.g.*, 1/8", 5/16", 7/16" etc.) or by standard wire gauge (S.W.G.) sizes. Most common sizes are 4, 6, 8, 10 and 12. The electrodes with higher SWG size number are thinner.
- Although any size electrode can be used for the job, but *for quick welding, the electrode size should be as large as permissible. Larger size electrodes permit heavier currents to be used hence, the metal deposition is faster and the job is done quicker. It must be, however, emphasised that choice of the electrode size does not determine the speed of the work. Good welds come out rapidly if consistent higher currents are used.*
  — Normally 12 SWG electrodes for welding can be used upto 3 mm plates or sections, 10 SWG upto 5 mm sections, 8 SWG upto 10 mm, 6 SWG upto 10/15 mm and 4 SWG for sections beyond 20 mm thickness.

- As the jobs get heated during welding, they should not be handled by naked hands. After the welding is over, the part may be put in *water for quick cooling*; otherwise it may be allowed to cool in open air. After this, the scum at the surface may be knocked out by welding hammer.
  — If *rebuilding* is being done, it is good practice to *beat the weld so that oversize grains are broken and this increases the strength of the joint.*

Typical data on use of "Mild steel electrodes" :

(*a*) ***Recommended currents :***

Electrode size		*Current range in amps.*	
SWG	*mm.*	*Min.*	*Max.*
10	3.25	95	125
8	4.06	140	170
6	4.88	160	220
4	5.89	200	275

(*b*) ***Composition (Chemical) :***

Carbon 0.09%
Manganese 0.47%
Silicon 0,20%
Sulphur 0.016%
Phosphorus ...... 0.34%.

13.8. WELDING OF VARIOUS METALS

Some welding methods/techniques as applied to different metals/alloys are briefly given below :

Metal /Alloys and Welding methods/Techniques :

1. Low carbon steels (or mild steel) :

- *Welded by :*
  — Forge welding;
  — Resistance welding;
  — Arc welding;
  — Gas welding.
- No flux required.
- Welding rods are made of pure iron or mild steel.
- No preheating is required even for welding thicker sections.
- In gas welding, a *neutral* flame is used in order to minimum oxidation of steel.

2. Medium carbon steels :

(Carbon content between 0.3 and 0.5%)

- *Welded by*
  — Arc welding;
  — Resistance welding;
  — Gas welding;
  — Thermit welding.

- The preheating temperature (varying from 100°C to 400°C) depends upon the carbon content in the steel.
- As this steel is harder and brittle than mild steel, therefore, it is necessary to *normalise* the components after the welding in order to relieve the residual stresses present in them.
- In gas welding, a slight *carburising flame* is used.

3. High carbon steels

(High %age of carbon)

- *Welded by* : Same as at (2).
- Preheating to about 400°C is essential.
- Sudden cooling should be avoided to avoid cracking along weld metal.
- Heat treatment of these steels after welding is necessary to a relieve residual stresses set up during welding.

4. Alloy steels :

(In addition to carbon, these steels contain small amount of nickel, chromium, molybdenum, manganese, silicon, copper. These steels may be low, *medium* and *high alloy steels*).

- The welding of low alloy steels is similar to the welding of medium or high carbon steels. *Shielded metal arc and submerged arc welding* are oftenly used.
- Preheating and slow cooling after welding is essential to obtain crack free welds *Welding of "stainless steel"* :
  - — Can be welded by oxy-acetylene and metal arc welding methods; best method being *electric butt welding* followed by prompt annealing between 730° to 800°C.
  - — A suitable electrode should be selected as per manufacturer's advice.
  - — For obtaining a sound weld, cleaning of edges to be welded and removal of slag after each run is necessary.
  - — Flux may or may not be used.

5. Cast steel :

- The *welding operation, for the repair of defective casting is termed as 'welding of cast steel'.*
- Gas welding with a *neutral flame* is usually used.
- Preheating of heavy casting is essential to minimise straining of metal due to local heating at the time of welding.

6. Cast-iron :

- *Welded by :*
  - — Metal arc welding ;
  - — Oxy-acetylene welding ;
  - — Braze welding.
- The weldability of cast iron usually decreases as the amount of free carbon in cast iron increases.
- The cast iron parts are generally preheated to a dull red heat and then welded.
- After welding, it is very important to anneal the casting.

7. Aluminium and its alloys :

(Cast and wrought forms)

- *Welded by :*
  - — Welding of all types including inert-gas and atomic hydrogen welding.
  - — The inert gas-tungsten arc welding is extensively used than other arc welding processes.
- In welding cast aluminium, preheating is necessary and after welding it should be cooled slowly.

8. Copper and its alloys :

- *Welded by :*
  - — Metal-arc welding
  - — Carbon-arc welding
- The direct current with straight polarity is usually employed for welding these metals.
- In gas welding of copper, a neutral flame and a filler rod of copper and silver alloy is used.

9. Nickel and its alloys :

- *Welded by :*
  - — May be easily welded by most of the major welding processes like metal-arc welding, resistance welding and oxy-acetylene welding.
- Pre-heat treatment and post-heat treatment are rarely used except for special cases.
- For welding nickel flux is not required.

13.9. REBUILDING

- Welding is used not only for fabrication of new parts but is used considerably for rebuilding of worn out parts, repair of *broken or cracked parts also.*
- *The worn out parts can be build up by use of proper electrodes. Where the high temperature required for welding might change the composition of the parent metal, low temperature or 'Eutectic' electrodes may be used.* After building up sufficient material the part can be re-machined to desired dimensions.
- This is done for *shafts, housings etc.*
- *Repair of cracked parts is also possible.* The cracked castings, bearing housings, broken gears etc. can be repaired this way. There is no difficulty of welding cracked mild steel, cast steel, manganese steel spares. However, cast iron and aluminium spares are difficult to weld. These require preheating and post heating so that the welding stresses do not weaken the repaired parts.

Thermit welding requires a special mould to be built up. A wax pattern is made around the gap and sand/clay mould is rammed outside it. A magnesite crucible contains charge and is mounted above the weld. After igniting crucible, the reaction takes about 30 seconds for completion. Metal is poured into the joint by removal of the tapping pin at the bottom of the crucible.

13.10. HARD FACING

- Welding is considerably used to reduce the wear on parts subjected to heavy abrasion,

such as *jaws of stone crushers, digging teeth of shovels, surfaces of rollers* etc. If austenitic steels are used for manufacturing, then the difficulty arises when any machining is required. Further these steels may not have sufficient shock absorbing capacity. To obtain it, the usual practice is to *hard the face of mild steel with harder deposits*. These may be machinable or may be completely unmachinable.

- This hard facing may be even used for austenitic manganese steel wearing parts *used in cement or stone crushing industries. These layers should not be thick and must not be used for building up.*
- *If the hard facing is to be done on worn out parts, these may have to be built up by ordinary electrodes, before hard facing is done.* This is carried out in layers and a good pining (hammering out) should be carried out before second layer is built up. Many electrodes are available in the market, by which longitudinal joints are welded in uniform fashion. This is called seam welding and is valuable in pipe manufacturing Water cooling is used to keep the electrodes cool.
- Hand facing gives 2 to 3 times the life in terms of wear as compared to plain wearing parts. This is very economical and requires less idle time for machines.

13.11. DEFECTIVE WELDS

A weld not properly welded is a *defective weld.* A properly made weld should have the following *characteristics :*

(*i*) The weld *should not crack in the bend test.*
(*ii*) It should not contain scum or slag imbedded in the well.
(*iii*) Its appearance should be ripple like and not spongy.
(*iv*) It should not have cavities and, and the grain size should be uniform.

- *Overcurrent tries to dissolve scum in the weld while undercurrent tries to give cracks in the weld.*
- If electrode distance from the weld is varying this will cause the uneveness of the weld.

13.12. UNDER-WATER WELDING

- Occasionally, welding has to be carried out under water and this is known as **"submerged welding"**. Obviously gas welding is not possible as the heat necessary for fusion cannot be generated under water by gas welding. However, submerged welding is possible by electric arc. *Heat generated by an electric arc in water is much lower than in open air welding hence special electrodes are used which have low fusion points and are not affected under water.*

  Under electric welding, the welding may be by 'arc' method or it may by 'resistance' method. In the arc *method* the arc passes between the electrode held in the holder with the welder and the job which is connected to the second terminal of the electric supply. The arc drawn between an electrode and the workpiece completes the electrical circuit. In *resistance welding,* current is passed through the two pieces held together under pressure. The *electric current causes heat in the joint due to eddy currents and loss of energy in the resistance of the circuit. This is also known as Thomson process.*

13.13. DEFECTS IN WELDS

Some of the defects encountered in the weld metal are :

1. Porosity and blow holes.
2. Inclusions.
3. Cracks.
4. Fish eyes.

1. Porosity and blow holes :

- These defects are produced when during solidification and cooling, the gases like hydrogen, oxygen and nitrogen are evolved as a result of sudden drop in solubility. The gases are absorbed by the molten weld metal from various sources including the atmosphere, fluxes and electrode coatings.
- Gas porosity is detrimental to the quality of welds and represents discontinuity in the metal structure. Supersaturation of the molten metal with gases and an excessively high cooling rate of the weld metal lead to the formation of blow holes.

2. Inclusion :

- Inclusions are the slag or non-metallic particles and are derived from the environments around the weld metal. Basic slags are more viscous and are difficult to remove from the molten metal.
- Slow cooling of the molten weld metal pool helps in the elimination of inclusions.
- The weldability of the parent metal is normally affected by the size and distribution of inclusions. Such inclusions that are formed by sulphur and phosphorus must be kept at a minimum. Aluminium, zirconium and the rare earth elements are known to greatly modify the shape, size and distribution of inclusions and thereby enhance most of the engineering properties of the welds.

3. Cracks :

- In steel welds, the cracks are the most serious defects.
- Cracks may be formed due to various causes including *unequal physical properties of the parent and weld metals, high stress conditions and faulty welding.* Normally these can be attributed to the metal characteristics, particularly to the *hydrogen content in the metal.* Cracks caused by hydrogen can appear in the etched, pickled, plated, heat treated parts, vessels holding hydrogen under pressure and in the welds.

Hot cracks. The weld metal cracks are called *hot cracks* because these appear as a result of stress and lack of ductility of the deposited metal at the high temperature. Low melting point compounds such as FeS that get deposited on the grain boundaries during solidification are usually responsible for a low ductility and the appearance of the cracks.

Cold cracks. These cracks are formed near the weld area and are due to *excessive cooling rates and the absorbed hydrogen.* Since these appear a long time after the welding operation when the material is cold, these are termed *cold cracks*. They constitute a great danger in the low alloy and high carbon steel welds.

4. Fish eyes :

- Fish eyes usually appear on the *fractured surfaces of the welded sections in the form*

of white areas, circular in shape and varying in size between 1 to 10 mm diameter. They always tend to form around inclusion and are frequently accompanied by microcracks.

- These are attributed to the presence of hydrogen in welds and the existence of stress conditions.
- The appearance of fish eyes in weld metal, after a small degree of low speed deformation, causes a drastic drop of weld ductility. But if the material is aged for a long time at room temperature or a few hours at higher temperature before testing, fish eyes are not formed and the ductility of the weld metal is high.

13.14. TESTING OF WELDED JOINTS

- It is very essential to have careful examination of the component at each stage of manufacture. Thus by inspection or quality control, the welding defects are located and preventive measures are devised to reduce or eliminate them.
- It is very difficult to ascertain whether the finished weld is up to the expected standard or not. In order to locate the defects and hidden flaws the welded portion may be inspected visually or examined with instruments.
  - The welded joints may be subjected to **destructive testing** like *tensile test, impact test, bending test, hardness* etc.
  - The **non-destructive tests** include *X-ray test, magnetic test, spark test, hydraulic test and air-pressure test for pressure vessels.*

13.15. EFFECT OF WELDING ON THE GRAIN SIZE OF THE METAL

During welding, there is an ample variation of temperature from molten metal of the weld to the edge of the heat-affected zone. Some of the metals have been heated far above the critical temperature, some just at the critical temperature, some not upto critical, and all the way down to the unaffected base metal. Thus, the gram size of the weld will be rather large. The grain size will become gradually small till the recrystallisation temperature is reached. The grain size will be minimum here and then will advance gradually again until it blends with the unaffected parent metal. In case of metals and alloys there is no transformation zone and only a gradual reduction of grain size from weld metal to the parent metal occurs. In heavy welds where several passes are required, the heat of each succeeding pass can be used to refine the grain of previous pass.

Effect of preheating on microstructure of the weld area in high carbon steel :

The microstructure of the weld area is determined by the rate at which cooling takes place in the weld area. The preheating before welding to some temperature (*e.g.*, 150° to 200°C) is thus carried out to reduce the rate cooling by lowering the temperature gradient (difference of temperature of molten metal and the original temperature of metal before welding). The temperature gradient produces the heat treatment of heated metal. Hard martensite may be formed in high carbon steels due to rapid cooling. This hardened steel at the heat-affected zone is less ductile, and thus is subjected to failure under impact loading.

Normally, *steel containing over 0.3% carbon should be preheated.* The preheat temperature varies with the type of metal and area of cross-section.

Preheating speeds up welding.

13.16. SOLDERING

13.16.1. Definition

Soldering *is an operation of joining two or more parts together by molten metal. It is a quick method of making joints* in light articles made from steel, copper and brass and for wire joints such as occur in electrical work. *Soldering should not be used where much strength is required,* or in case *where the joint will be subjected to vibration or heat, as solder is comparatively weak and has a low melting point.* When joints must stand these treatments they should be riveted, welded or brazed.

13.16.2. Types of Solder

Roughly there are two types of solder :

1. Soft solder, which is usually a *lead-tin mixture.*
2. Hard solders, which may be roughly grouped into the following sub-division :
   (*i*) Brass solders (copper-zinc alloy).
   (*ii*) Silver solders (copper-silver alloy).
   (*iii*) Copper solders.
   (*iv*) Nickle-silver solders.

13.16.3. Selection of Solder

When choosing any solder containing zinc the question of the solder setting up a *galvanic action should be examined.* With some *brass articles* this is very likely. The solder must be chosen in relation to the material of which the articles to be joined are made. In each instance the melting point of the solder should, where possible, be several hundred degrees below that of the metals to be united. Articles made in brass, copper, phosphor bronze or nickel-silver are both hard soldered and soft soldered. *If an assembly is subjected to vibration, then a silver solder should be chosen.* This is particularly necessary on pipe work for engines, and experience over many years indicates that silver solder of the correct grade cannot be improved upon for such articles.

13.16.4. Flux or Soldering Fluid

During the operation of a soft soldering a *flux is necessary to cover the surface of the components and solder with a film so that the formation of an oxide is prevented and the solder aided in its flow around or along the joint.*

Fluxes are of two kinds :

1. *Those which not only protect the surface, but play an active chemical part in cleaning it.* These are *most efficient.*

Examples : *Zinc chloride* ("killed spirits"), *ammonium chloride and zinc ammonium chloride,* a combination of the two.

Killed spirits gives the best all-round results and is extensively used, but care is necessary to ensure that the articles are thoroughly *washed afterwards* so that the acid does not attack the metal.

Killed spirits is muriatic (hydrochloric) acid in which pure zinc has been placed. The acid attacks the zinc, and much gas is liberated. When the acid cannot take up any more of the zinc it is said to be killed.

2. *Those which merely protect a previously cleaned surface.* **Examples :** Tallow, resin, vaseline, olive oil etc. and in addition to these there are various patent fluxes of which "Fluxite" is a well known example.

When the nature of the work is light and continuous, the problem of fluxing is greatly facilitated by using one of the strip solders with the flux incorporated. One such solder is *resin cored,* being in the form of a small thin tube having a core of resin which melts and fluxes the work as the solder is consumed.

13.16.5. Soldering Equipment

Soldering equipment broadly includes soldering iron and soldering gas stove/heater.

(*a*) **Soldering iron** : It *is a tool used during a soldering operation to heat the solder and the parts to be jointed.* Soldering irons are of two main types :

(*i*) Those heated by either solid or gaseous fuel;

(*ii*) Those *heated electrically.*

An ordinary soldering iron consists of a copper point or "*bit*", usually of *square or rectangular cross-section-a stem, usually of mild steel and a wooden handle.* The point is of a size chosen to suit the class of work, *its purpose is to absorb heat while in the fire or muffle, and to give this out when applied to the job,* thus heating the two parts and melting the solder. The point is tinned that is covered with solder, and should be kept clean.

When applying the iron it must be held in position for a sufficiently long time to ensure that the work is heated to the required temperature, it is then drawn slowly over the surface so that it will heat the adjoining area and melt the solder. The stem forms the connection between the point with its heat and high conductivity and the handle with its low conductivity which permits the tool to be easily manipulated.

When small assemblies have-to be soft-soldered, an electrically heated iron proves exceedingly useful and is often far better than the type requiring solid or gaseous fuel for heating.

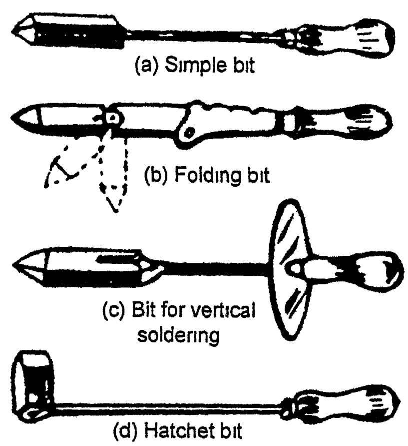


Fig. 13.39. Soldering bits.

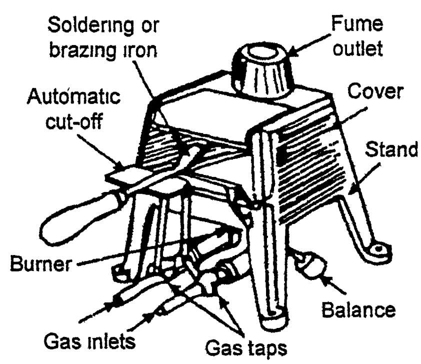


Fig. 13.40. Soldering gas stove/heater.

Fig. 13.39 shows various types of soldering bits.

(*b*) **Soldering gas stove/heater :** Fig. 13.40 shows a soldering gas stove/heater used for heating the soldering bit for accomplishment of soldering operation.

13.16.6. Soldering Procedure

The *process of soldering is carried out as follows :*

1. The surfaces of the pieces to be joined must be thoroughly cleaned and made free from rust, grease, oil and dirt by scraping with dull knife or emery paper.
2. Then coat the surfaces with flux.
3. Take a blob of solder on the bit of the hot soldering iron and allow it run down hill filling the recess of the joints for light work. For heavy work the hot iron should be held against the soldering stick and molten solder be allowed to fill the longer length of the joint.
4. Wipe off excess of solder with a piece of felt or cotton waste.
5. Wash the joint thoroughly with warm water to remove the traces of acid flux.

13.16.7. Characteristics of a Good Joint

A *small amount of solder and perfect adhesion* are characteristics of a good joint. While carrying out tests on joints it has been established that the best joints are those in which thickness of solder varies between 0.0075 and 0.05 mm. It has been observed from experiments that the *thinner the layer of solder, the higher the soldering temperature necessary for maximum strength.*

13.16.8. Important Tips for Effective Soldering Operation

1. Always use an iron as large as can be handled and in the direction of having it too hot rather than not hot enough: it should not, of course, be red hot.
2. A better joint can be made if the work is warm than cold.
3. Iron tinning is facilitated by having some blobs of solder in a tin lid with a little spirits and touching both the spirits and the solder at the same time.
4. Quenching the hot joint in spirits, or painting on spirits whilst hot, will often effect remarkably thorough cleaning.

13.16.9. Advantages of Soldering

The *advantages of soldering are :*

1. Low cost.
2. Simplicity and cheapness of the equipment.
3. The properties of base metal are not affected due to low operating temperature.
4. Good and effective sealing in fabrication as compared to other process like riveting, spot welding and bolts.

13.16.10. Applications of Soldering

The soldering, in practice, is done for the following work :

1. Connections in wireless set (radio), T.V. sets etc.

2. Wiring joints in electrical connections, battery and other terminals.
3. Drain water gutters and pipes.
4. Radiator brass tubes for motor car.
5. Copper tubing carrying liquid fuel, gas or air used on engines.
6. Brass halved bearings are joined with solder when relined with white, metal and bored on lathe.
7. When halved bearings are to be lined with babbit metal.
8. It is sometimes used to repair utensils.

Table 13.2 gives the details of soft solders.

TABLE 13.2
Soft Solders

S.No.	*Purpose for which solder is used*	*Tin %*	*Lead %*	*Antimony %*	*Melting range °C*	*Remarks*
1.	Plumber's piped joints	30	69	1	180-250	Prolonged pasty stage when melting or solidifying.
2.	Tinsmith's general work and hand soldering	45	52.5	2.5	180-210	Solidifies fairly rapidly.
3.	Tinsmith's and copper smith's fine work. Hand soldering	50	47.5	2.5	180-210	Solidifies fairly repidly.
4.	Steel tube joints.	65	35	—	180	Solidifies quickly. No pasty stage.

13.16.11. Types of Soldered Joints

In *soft soldering,* the only types of joint used is the *'lap joint'*. The lap should be 3 to 60 mm depending on the thickness of the metal and the working conditions of the joint. On thickness from 2 to 5 mm and a pressure of upto 5 bar (gauge), the lap should be at least 40 mm and the joint should be designed to work in shear. *In brazing, the most commonly used type of joint is also the 'lap joint'.* The other types of joints used in soldering practice are shown in Fig. 13.41.

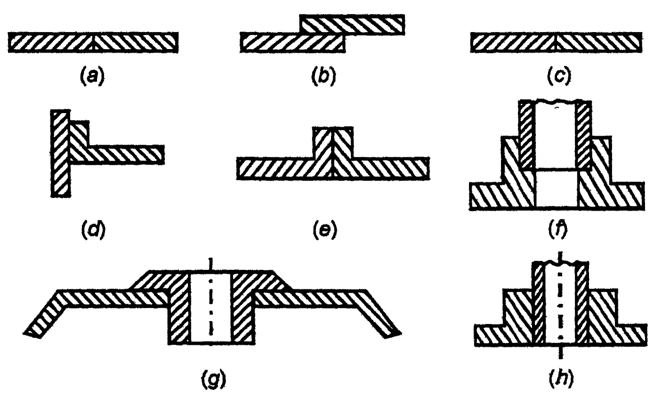


Fig. 13.41. Soldering joints.

The factors which govern the strength of a joint are the area of the

joint (or lap), the lift-up of members to be joined and the clearance between them. The clearance, though, is of importance to the strength of the soldered joints in high-strength metals, while in low-strength metal it is of minor consequence.

The clearance should be kept to a minimum to facilitate capillary attraction of the molten solder and to produce the strongest joint. When a clearance is sufficiently small, the metal of the joint is an alloy of the 0.2-0.25 mm. In soldering with silver alloys, it should be 0.5-0.03 mm.

13.17. BRAZING

13.17.1. Introduction

Brazing *is a soldering operation using brass as the joining medium.* The brazing operation is simply a form of *hard soldering using a copper-zinc alloy,* that is, brass, as the uniting medium (the term hard soldering is used because the welding alloy used in the joint is harder than solder, naturally the joint is much more stronger than soldering ?

The brass used for making the joint in brazing is generally called *"spelter"* and its composition depends upon the metal being brazed because it is essential that the spelter shall have a lower melting point than the material being jointed.

Three brazing alloys are :

1. *Copper* = 70%, *Zinc* = 30%; Melting point = 960°C
2. *Copper* = 60%. *Zinc* = 40%; Melting point = 910°C
3. *Copper* = 50%. *Zinc* = 50%; Melting point = 870°C.

When brazing or hard soldering using a brass mixture, the heating may be by means of :

(*i*) Coal-gas and a mouth blow pipe for very small work.
(*ii*) Coal-gas and compressed air using the normal blow pipe.
(*iii*) Oxy-acetylene torch.
(*iv*) Oxy-hydrogen torch.
(*v*) Coal-gas and oxygen with a suitable torch.
(*vi*) Electrical resistance as on a spot welder.

13.17.2. Fluxes

When hard soldering, the chief flux is *borax,* which may be obtained in powder, granulated or stick form. It may be dissolved in hot water to form a paste and is then applied to the joint by means of a brush. Slick *borax* is supplied in the form of a cone, and is rubbed down on a rough slate with water to form a paste. In this condition it is applied to the joint, preferably with a brush.

The action of the flux is *three fold:*

(*i*) *It is used to prevent an oxide forming along the joint faces as they are heated.*
(*ii*) *A cleansing medium to remove the dirt.*
(*iii*) *It aids the capillarity of the molten metal and facilitates its flow around and through the joint.*

13.17.3. Brazing Equipment

The brazing equipment mainly comprises a *blow pipe* (Fig. 13.42) and *brazing hearth* (Fig. 13.43). The heat for brazing is obtained by a blow pipe fed with coal gas, and air at a slight pressure. When heating of the work is taking place it is advisable to make the most of the heat given out from the blow pipe flame, and for this reason a small sheet-metal hearth containing fire brick or coke should be used. If the work is placed upon a substance heat is reflected back on its underside and this conserves the heat during the operation.

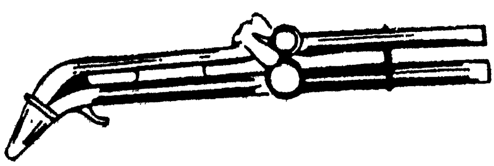


Fig. 13.42. Blow pipe.

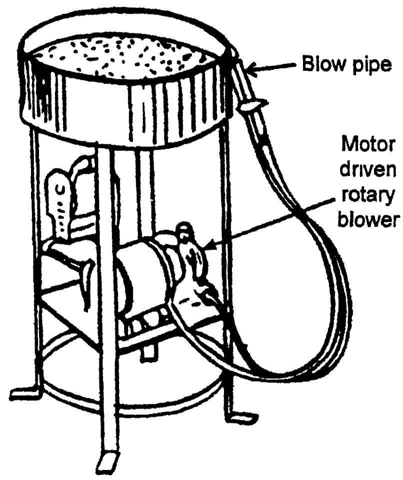


Fig. 13.43. Brazing hearth.

13.17.4. Brazing Procedure

The *process of brazing is carried out as follows :*

1. The surfaces to be joined are thoroughly cleaned.
2. Then a paste made of flux and spelter is kept in the joint, the joint being held in position by suitable clamps or tongs.
3. The flame is directed over the joint held on a fire brick piece. The flux and spelter will soon melt and fill the recess between the joint.
   The liquid is spread uniformly over the joint either with a pointed wire piece or by moving the jet of flame circular over the joint.
4. When the joint is hot common salt is put to soften the glossy hard flux that sets over the joint.
5. The work is removed from the clamp after it is cooled.

13.17.5. Applications of Brazing

The field of application of brazing includes the following :

1. Parts of bicycle such as frames and rims.
2. Pipe joints subjected to vibrations.
3. Exhaust pipes in motor engines.

4. Band saws.
5. Tipped tools.
6. Nipples and unions to M.S. and copper tubing.

13.17.6. Silver Soldering

The melting temperature of most silver solders is little lower than that of spelter used for brazing and so the *operation of silver soldering is somewhat easier to carry out than brazing.* A joint made by silver solder is not so strong as a brazed one but is stronger than the soldered joint. For different work, silver solders with varied composition of silver, copper and zinc are used.

Calcined borax and powdered glass are the suitable *fluxes.* Before silver soldering, the joint is pickled in the dilute sulphuric acid. The process of silver soldering is carried out with a blow-pipe and spirit lamp or oil lamp directing the flame to the joint only for melting the flux and silver solder. Clamps of various types are used to hold the work in position while joint is being made. Small thin pieces or filings of silver solder are mixed with flux and water. This mixture formed in a paste is kept in between the joint before the flame is blown through the blow pipe. Work is held either over a charcoal piece or fire brick for retaining heat at the joint. After the joint is done by silver soldering, the flux starts setting hard and glossy over the joint, which is softened by putting the common salt. *Unlike and like metals can be joined together.*

Table 13.3 gives the composition, melting point and uses of some of the important silver solders.

TABLE 13.3
Silver Solders

S.No.	*Composition %*	*Melting point*	*Uses*
1.	Ag = 20, Cu = 52, Zn = 38	820°C	Used for practically for all non-ferrous alloy (except aluminium and steels and iron).
2.	Ag = 20, Cu = 45, Zn = 35	775°C	
3.	Ag = 80, Cu = 16, Zn = 4	740°C	
4.	Ag = 45, Cu = 30, Zn = 25	675°C	

13.18. COMPARISON OF WELDING AND ALLIED PROCESS

The comparison of welding and allied process is given in tabular form below :

TABLE 13.4
Comparison of Welding and Allied Process

S. No.	*Process*	*Advantages*	*Limitations*
1.	*Forge welding*	(*i*) Inexpensive equipment. (*ii*) Semi-skilled operation.	(*i*) Poor joint strength. (*ii*) Labour intensive process (low production rate). (*iii*) Weld quality dependent on operator's skill. (*iv*) Can be used only where hammering is possible.

2.	*Resistance spot welding*	(*i*) High production rate. (*ii*) Very economical process. (*iii*) High skill not required. (*iv*) Most suitable for welding sheet metals. (*v*) Dissimilar metals can be welded. (*vi*) Small heat affected area.	(*i*) Suitable for thin sheets only. (*ii*) High equipment cost.
3.	*Gas welding*	(*i*) Good weld quality. (*ii*) Portable low cost equipment. (*iii*) Suitable for repair work and low quantity production.	(*i*) Manual operation hence low production rate. (*ii*) Skilled operator required. (*iii*) Difficult to prevent contamination. (*iv*) Large heat affected zone.
4.	*Electric arc welding*	(*i*) Portable and relatively inexpensive equipment. (*ii*) Very versatile process.	(*i*) Large heat affected zone. (*ii*) Weld quality depends upon operator's skill in manual operations. (*iii*) Not suitable for thin sections.
5.	*Thermit welding*	(*i*) Can be used anywhere. (*ii*) Low set-up cost. (*iii*) Not a highly skilled operation. (*iv*) Most suitable for welding of thick sections.	(*i*) Only thick sections can be welded. (*ii*) High set-up and cycle time.
6.	*Laser beam welding*	(*i*) High depth-to-width ratio of weld. (*ii*) Good weld quality. (*iii*) Dissimilar metals can be welded. (*iv*) Suitable for thin sections. (*v*) Welding can be done in inaccessible locations. (*vi*) Minimum distortion. (*vii*) High production rate.	(*i*) Highly skilled operation. (*ii*) High equipment cost. (*iii*) Eye protection required. (*iv*) Suitable for welding narrow and deep joints.
7.	*Soldering*	(*i*) Suitable for making leak proof joints. (*ii*) No distortions. (*iii*) Low equipment cost.	(*i*) Joints suitable for low temperature applications. (*ii*) Low joint strength.
8.	*Brazing*	(*i*) Not much skill is required. (*ii*) Good joint strength. (*iii*) Dissimilar metals can be joined. (*iv*) Suitable for joining intricate and light weight shapes. (*v*) Very little distortion. (*vi*) Low equipment cost.	(*i*) Not suitable for thick sections. (*ii*) Joint strength not as high as in gas or arc welding. (*iii*) Joints not suitable for high temperature applications. (*iv*) Joint colour may not match with base metal.

QUESTIONS WITH ANSWERS

Q. 13.1. Explain briefly 'Friction welding processes'. State also its advantages and limitations.

Ans. In this welding processes (Fig. 13.44) the two surfaces to be welded are rotated relative to each other under light normal pressure. When the interface temperature increases due to frictional rubbing and when it reaches the required welding temperature, sufficient normal pressure is applied and maintained until the two pieces get welded.

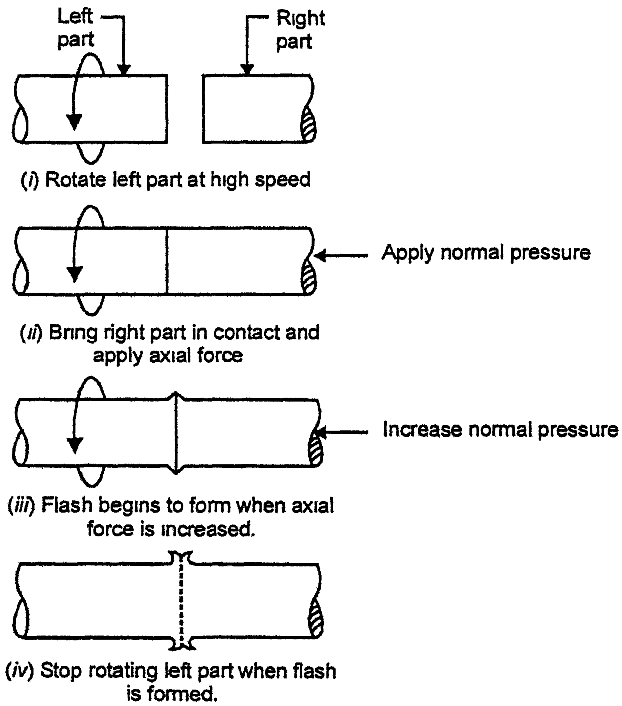


Fig. 13.44. Friction welding.

Advantages :

(*i*) High production rate.
(*ii*) Good weld strength.
(*iii*) Can weld dissimilar metals.
(*iv*) Narrow heat affected zone.

Limitations :

(*i*) Can be used only when some rotational symmetry exists.
(*ii*) High equipment cost.

Q. 13.2. Describe briefly 'Explosive welding process'. What are its advantages and limitations ?

Ans. In this process welding is achieved through very high contact pressure developed by

detonating a thin layer of explosive placed over one of the pieces to be joined (Fig. 13.45). The detonation imparts high Kinetic energy to the piece which on striking the other piece causes plastic deformation and squeezes the contaminated surface layers out of interface resulting in a high quality welded joint.

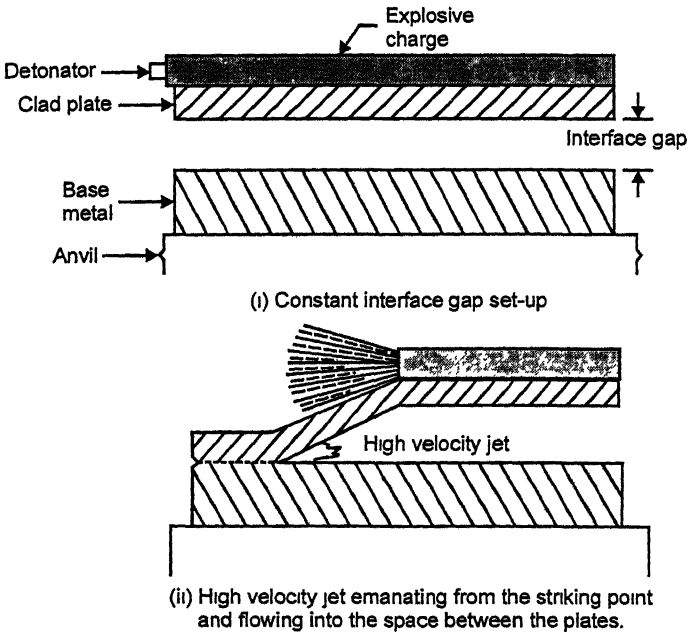


Fig. 13.45. Explosive welding process.

Advantages :

(i) High joint strength.
(ii) Dissimilar metals can be welded.
(iii) Inexpensive equipment.
(iv) Large size plates can be welded.
(v) Good for plate cladding.

Limitations :

(i) Trained operators are required.
(ii) Inherently dangerous processes.
(iii) High setup time.

Q. 13.3. What is a soldering process ? What is a soft solder and a hard solder ?

Ans. Soldering *is a process of joining two metals with low melting point metal.* The manual soldering method involves using a hand type soldering iron made of copper. It is heated to a temperature 300°C and its tip is dipped in flux and tinned with solder. Next, the soldering iron is used for heating base metal as well as for melting and spreading the soleter.

Solder alloys. These alloys fall into the following three groups :

(i) Those which melt below 313°C;

(*ii*) Those which melt between 313° — 371°C.

(*iii*) Those which melt between 371°C — 427°C.

The low melting point solder which contains a eutectic combination 60% lead and 40% tin is called 60-40 solder; it melts at 183°C. Zinc, cadmium and silver are added to solders to increase their melting point. The former is called soft solder whereas the latter are hard solders (high shear strength).

Q. 13.4. Explain the process of joining in brazing and discuss the influence of gap on the strength of the joint.

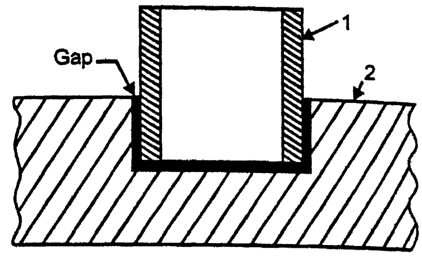


Fig. 13.46.

Ans. Brazing is a joining process between parts 1 and 2 (say) with braze metal placed in the gap (a clearance) and heat applied to the work material. *Brazed joint is formed by capillary action.* It is essential to have *optimum gap* between two parts. *Too much gap is not desirable;* at the same time *too little a gap will leave the joint unbrazed at some points and affect the strength.*

Q. 13.5. Differentiate between pressure welding and fusion welding.

Ans. Pressure welding. Solid state welding may be carried out at room temperature or at elevated temperature. The joint is formed *owing to plastic flow at the joint due to applied pressure.* In pressure welding at high temperature, heat is generated due to resistance at the joint due to flow of current being high. Other methods of achieving high temperature include friction, induction heating, impact energy as in the case of explosive welding. Seam welding, projection welding, butt welding are well known resistance welding techniques.

Fusion welding. In fusion (or liquid state) welding the material around the joint is melted in both the parts to be joined. If necessary a molten filler metal is added from a filler rod (or otherwise). The important zones in fusion welding are : (*i*) Fusion zone; (*ii*) Heat affected unmelted zone around the fusion zone; (*iii*) The unaffected original part.

Important factors affecting fusion welding process are :

(*i*) Nature of weld pool.

(*ii*) Chemical reaction in the fusion zone.

(*iii*) Characteristics of heat source.

(*iv*) Contraction, residual stresses and metallurgical changes.

(*v*) Heat flow from the joint.

Q. 13.6. What is the fundamental feature that distinguishes solid state welding from liquid-state welding ?

Ans. The fundamental feature which distinguishes solid-state welding from liquid-state welding is the process by which two parts are joined together by heating them to fuse in *liquid form without fuse.* In liquid-state welding also called arc welding, an electric arc is used to melt and then join the work to be welded. While in solid-state welding the joint is made without heating the work to fuse; the joint is made by explosion pressure or other methods.

The following methods of solid-state welding clearly give idea of doing solid-state welding and how it differs from liquid-state welding.

(*i*) *Friction welding.* In this process one of the parts to be welded is held in the head stock of a lathe like friction welding machine and the other is rotated and pressed against its surface.

(*ii*) *Explosive welding.* In this type of welding, strong metallurgical bonds are produced between solid metal surfaces by impacting one over another at a very high speed.

(*iii*) *Forge welding.* This method involves heating of the solids to their plastic state and then hammering the ends to be joined.

(*iv*) *Ultrasonic welding.* In the method two solids to be joined together are tightly pressed against each other and given relative movement (vibration) at frequency between 2 kHz to 6 kHz for a short interval.

Q. 13.7. What are the qualities of flame used for welding ?

Ans. A welding flame should possess the following *qualities :*

1. Must not burn the metal (oxidise it).
2. High temperature to melt the metals.
3. Products of combination should not be toxic.
4. Very intense concentrated flame so that a spot under the flame becomes molten and forms a liquid puddle.
5. Must not add dirt or foreign material to the metal.

Q. 13.8. Name the commercially used gas welding and cutting flames.

Ans. The commercially used gas welding and cutting flames are :

- Oxygen — acetylene
- Oxygen — hydrogen
- Oxygen — natural gas or artificial gas
- Oxygen — liquefied petroleum gas.

Q. 13.9. Name the common welding troubles.

Ans. The common welding troubles are :

(*i*) Warping
(*ii*) Porous welds
(*iii*) Poor penetration
(*iv*) Distortion
(*v*) Undercutting
(*vi*) Cracked welds
(*vii*) Magnetic blow
(*viii*) Brittle welds
(*ix*) Spatter
(*x*) Poor appearance
(*xi*) Poor fusion.

Q. 13.10. What are the advantages of Gas Metal Arc Welding (GMAW) or Metal Inert Gas (MIG) welding ?

Ans. Following are the advantages of GMAW or MIG :

1. Flux not required.
2. High welding speeds are possible.
3. Process can be automated.
4. High corrosion resistance.
5. The metals like aluminium and stainless steel, which are difficult to weld, can be welded.

Q. 13.11. Which gases are used for welding the following materials by GMAW or MIG processes ?

(*i*) Stainless steel

(*ii*) Steel

(*iii*) Copper or aluminium

(*iv*) Copper-nickel and high-nickel alloys

(*v*) Titanium.

Ans. Following gases are used for welding various materials by GMAW or MIG process:

(*i*) Stainless steel : *Argon-oxygen or helium-argon mixtures.*

(*ii*) Steel : CO_2.

(*iii*) Copper or aluminium : *Argon or argon-helium mixtures.*

(*iv*) Copper-nickel and high-nickel alloys : *Argon-helium mixtures.*

(*v*) Titanium : *Pure argon gas.*

Q. 13.12. What are the advantages of submerged arc welding ?

Ans. Following are the *advantages of submerged arc welding :*

1. Less distortion.
2. Fewer passes are required due to deep penetration.
3. Much faster a process.
4. No edge preparation is required.
5. Operator is not exposed to usual spatter and can work without helmet and other safety equipment.
6. It is often used in automatic mode.

Q. 13.13. What are the applications of gas welding ?

Ans. Following are the *applications of gas welding :*

1. To join most ferrous and non-ferrous metals, *e.g.*, carbon steels, alloy steels, cast iron, aluminium, copper, nickel, magnesium and its alloys etc.
2. To join thin materials.
3. To join materials in whose case excessively high temperatures would cause certain elements in the metal to escape into the atmosphere.
4. To join materials in whose case excessively high temperatures or rapid heating and cooling of the job would produce unwanted or harmful changes in the metal.
5. Automative and Aircraft industries.
6. Sheet metal fabricating plants etc.

Q. 13.14. What are the advantages and applications of spot welding ?

Ans. Following are *the advantages and applications of spot welding :*

Advantages :

(*i*) High uniformity of products.

(*ii*) No edge preparation is needed.

(*iii*) Low cost.

(*iv*) High speed of welding.

(*v*) Operation may be made automatic or semi-automatic.

(*vi*) Dependability.
(*vii*) More general elimination of warping or distortion of parts.
(*viii*) Less skilled worker required.

Applications :

(*i*) Automobile and aircraft industries.
(*ii*) Containers such as receptacles and tote boxes frequently are spot welded.
(*iii*) Spot welding of two 12.5 mm thick steel plates has been done satisfactorily as a replacement for riveting.
(*iv*) The attachment of braces, brackets, pads or clips to form sheet metal parts such as cases, covers, bases or trays is another application of spot welding.
(*v*) Many assembling of two or more sheet metal stampings that do not require gas tight or liquid tight joints can be more economically joined by spot welding than by mechanical methods.

Q. 13.15. What are the applications of 'Butt Welding' ?

Ans. The applications of Butt welding are :

1. To weld longitudinal butt joints in tubing and pipe and traverse butt joints in heavy steel rings.
2. To weld small ferrous and non-ferrous strips and rods.
3. In wire drawing industries where wire drawing would be impossible without the upset butt welding process.
   - Butt welding has been largely replaced by flash welding.

Q. 13.16. Name the metals welded by flash welding.

Ans. The *following metals can be welded by flash welding :*

(*i*) Low carbon steels.
(*ii*) Medium strength and high strength low alloy steels.
(*iii*) Tool steels.
(*iv*) Stainless steels.
(*v*) Aluminium alloys (with thickness greater than 1.25 mm).
(*vi*) Copper alloys (with high zinc content).
(*vii*) Magnesium alloys.
(*viii*) Molybdenum alloys.
(*ix*) Nickel alloys.
(*x*) Titanium alloys.

Q. 13.17. What are the advantages and disadvantages of atomic hydrogen welding ?

Ans. Following are the *advantages and disadvantages of atomic hydrogen welding :*

Advantages :

1. No flux or separate shielding gas is used; hydrogen itself acts as a shielding gas and avoids weld metal oxidation.
2. Due to high concentration of heat, welding can be carried out at fast rates (specially when filler metal is not needed) and with less distortion of the workpiece.

3. Welding of thin materials is also possible which otherwise may not be successfully carried out by metallic arc welding.
4. The job does not form a part of the electrical circuit. The arc remains between two tungsten electrodes and can be moved to other places easily without getting extinguished.

Disadvantages :

1. For certain applications, the process becomes uneconomical because of higher operating cost as compared to that of other welding processes.
2. The process cannot be used for depositing large quantities of metals.
3. Welding speed is less as compared to that of metallic arc or MIG welding.

Q. 13.18. How are soldering methods classified ?

Ans. Soldering methods are best classified by the method of heat application. The heat should be applied in such a manner that the solder melts while the surface is heated to permit the molten solder to wet and flow over the surface.

The various soldering methods are :

1. Soldering iron method.
2. Torch method.
3. Dip and wave methods.
4. Induction method.
5. Resistance method.
6. Furnace and hot plate method.
7. Spray method.
8. Ultrasonic method.
9. Condensation method.

Q. 13.19. Explain briefly soft soldering and hard soldering.

Ans. Soft soldering. It is used extensively in *sheet-metal work* for joining parts that are *not exposed to the action of high temperatures and are not subjected to excessive loads and forces.* It is also employed for *joining wires and small parts.*

- The solder, which is mostly composed of lead and tin has a melting range of 150 to 350°C. A suitable *flux* is always used in soft soldering. *Its function is to prevent oxidation of the surfaces to be soldered or to dissolve oxides that settled on the metal surfaces during the heating process.* Although corrosive, *zinc chloride* is the most common soldering flux. Rosin is non-corrosive, but it does not have the cleaning properties of zinc chloride.
- A blow torch or soldering iron constitutes the equipment for heating the base metals and melting the solder and the flux.

  Hard soldering. It employs solders which *melt at higher temperatures* and are *stronger* than those used in soft soldering.
- *Silver soldering is a hard soldering method*, and *silver alloyed with tin is used as solder.* The temperatures of the various hard solders vary from 600 to 900°C. The *fluxes are mostly in paste form and are applied to the joint with a brush before heating.*

Q. 13.20. What do you mean by 'Weldability' ?

Ans. Weldability *is the capacity of a material to be welded under the fabricating conditions imposed into a specific suitably designed structure and to perform satisfactorily in the intended surface.* This implies that a metal with good weldability can be welded readily so as to perform satisfactory in the fabricated structure.

Q. 13.21. What are the characteristics of a good weld ?

Ans. A *good weld should have the following characteristics :*

1. Absence of surface defects like blow holes, inclusion and incomplete penetration.
2. Absence of surface defects like overlap, undercut, cracks, crate and surface porosity.
3. Even contour of weld.
4. Uniformly rippled surface of weld.
5. Even width of the weld.

Q. 13.22. What points should be kept in view to avoid the weld defects ?

Ans. Following points should be kept in view *to ensure a correct weld :*

1. To maintain proper arc length.
2. To do preperly the joint preparation of the workpiece to be welded.
3. To use correct welding.
4. To select the electrode of correct type and size.
5. To select the welding current according to the nature of job.

Q. 13.23. State the effects of current and voltage on the quality of weld.

Ans. The *effects of current and voltage on the quality of weld* are as follows :

(*i*) *Too high current*	Gives deeper crater and penetration, flat bead, much spatter, electrode becomes red hot etc.
(*ii*) *Too low current*	Imparts poor penetration, shallow crater, weld overlapping on the plate etc.
(*iii*) *Too high voltage*	Produces a fierce wandering and noisy hissing arc, bead is often porous and flat, spattering of metal.
(*iv*) *Too low voltage*	Causes sticking of electrode with work and arc becomes difficult to maintain, weld is deposited in blobs with no penetration etc.

Q. 13.24. Name the fluxes used for welding the following metals :
(*i*) Copper and its alloys
(*ii*) Aluminium
(*iii*) Cast iron.

Ans. (*i*) ***Copper and its alloys :***

- Boric acid
- Borax
- Boric acid 50%, Borax 50%.
- Boric acid 35%, Borax 50%, Sodium phosphate 15%.
- Borax 56%, Potassium carbonate 22%, Sodium chloride 22%.

(*ii*) *Aluminium :*

- Sodium chloride 30%, Potassium chloride 45%, Lithium chloride 15%, Potassium fluoride 7%, Sodium bisulphate 3%.

- Sodium chloride 28%, Potassium chloride 50%, Lithium chloride 14%, Sodium fluoride 8%.
- Sodium chloride 19%, Potassium chloride 29%, Barium chloride 48%, Fluorspar 4%.

Aluminium fluxes must be stored in hermetically sealed cans.

(*iii*) ***Cast Iron :***

- Borax.
- Borax 56%, Sodium carbonate 22%, Potassium carbonate 22%.
- Borax 23%, Sodium carbonate 27%, Sodium nitrate 50%.

Q. 13.25. What are the functions of 'Electrode coatings' ?

Ans. The *electrode coatings perform the following functions :*

1. Stabilize the arc.
2. Perform the metallurgical refining operations.
3. Provide a protecting atmosphere.
4. Facilitate overhead and position welding.
5. Slow down the cooling rate of the weld.
6. Increase the deposition efficiency.
7. Reduce spatter of weld metal.
8. Remove oxides and impurities.
9. Influence the depth of arc penetration.
10. Provide slag of suitable characteristics to protect the molten metal.

Q. 13.26. Explain briefly induction welding ?

Ans. In induction welding *coalescence is produced by the heat obtained from the resistance of the weldment to the flow of an induced electrical current.* Pressure is frequently used to complete the weld. The inductor coil is not in contact with the weldment; the current is induced into the conductive material. Resistance of the material to this current flow results in the rapid generation of heat. In operation a high current is induced into both edges of the work close to where the weld is to be made. *Heating to welding temperature is extremely rapid and the joint in completed by pressure rolls or contacts.*

Vacuum tube oscillators are the source of power for most high frequency welding.

- Induction welding can be used for most metals and has been successfully employed for some dissimilar metals. Applications include the *butt and seam welding of pipe, sealing containers, welding expanded metal and fabricating various structural shapes from flat stock.*

Q. 13.27. Give the comparison between soldering and brazing.

Ans. The comparison between soldering and brazing is given below :

S.No.	*Aspects*	*Soldering*	*Brazing*
1.	*Melting point of filler metal.*	Below 400°C.	Above 400°C.
2.	*Stability of joints made.*	Less.	More.
3.	*Effect of high pressure and temperature on the joint.*	Joints are affected.	Joints are not affected.
4.	*Cost of the equipment.*	Very low.	Comparatively high.

Q. 13.28. What is diffusion welding ? Explain.

Ans. Diffusion Welding (DFW), *also called a diffusion bonding, is the process of joining two parts purely by the diffusion. The diffusion can be achieved by keeping the two pieces in intimate contact under pressure.* The pressures used are in the range of 35 to 70 MPa, because of the large contact areas used. The diffusion being a rate process, can be accelerated by the use of heat, though is not essential. By the application of heat, the bonding time can be reduced from hours to minutes. A *filler metal is generally used and kept in between the two plates to be joined.*

- *Diffusion welding can be used for joining metals to metals as well as metals to non-metals.* The weld is very neat requiring no further processing on the joint.
- *Diffusion welding is more expensive and, therefore, can only be justified for closer tolerance work or for expensive materials.*

Q. 13.29. What are the advantages of A.C. arc welding ?

Ans.
- The major advantage of A.C. arc welding is *complete absence of magnetic arc blow and thus quality welds are produced.*
- Once the arc is started, it is easy to control and maintain it.
- It is usually faster because large electrodes and more current can be used due to minimum magnetic blow conditions.
- It is very well suited to weld aluminium and is very popular for welding on heavy gauge steel.

Q. 13.30. Why is it difficult to start A.C. arc ? How is it simplified in practice ?

Ans. It is difficult to start A.C. arc *because of alternating current flow.* This difficulty is overcome by having hot start circuit which provides an extra flow of very high frequency current at the time of striking the arc. In some machines, capacitors are employed in arc (secondary) circuit to give high current surges for the arc striking.

Q. 13.31. What is arc blow ? Explain.

Ans. Arc blow is *the phenomenon of wandering of arc and it occurs in D.C. welding.*

When a current flows in any conductor, a magnetic field is formed around the conductor at right angles to the current. Since in the case of D.C. arc welding, there is current through the electrode, arc, workpiece and ground clamp, magnetic field exists around each of these components. The arc thus lacks control as though it were being blown to and by the influence of these complex magnetic fields. This is more common in welding with very high or very low currents, and especially in welding in corners or other confined spaces. Usually arc blow results from the interaction of magnetic fields of the electrode workpiece with that of the arc. *The movement of arc blow causes atmospheric gases to be pulled into the arc, resulting in porosity or other defects.*

Q. 13.32. What are the advantages of brazing ?

Ans. Following are the *advantages of brazing :*

1. Cast and wrought metals can be joined.
2. Metallurgical properties of the base materials are not seriously disturbed.
3. Assemblies can be brazed in a stress free condition.

4. Dissimilar metals can be joined.
5. Non-metals can be joined to metals, when the non-metal is coated.
6. Materials of different thickness can be joined easily.
7. Complex assemblies can be brazed in several steps by using filler metals with progressively lower melting temperatures.
8. Little or no finishing is required by the brazed joints.

Q. 13.33. What is 'Stud arc welding' ?

Ans. Stud arc welding is *semi-automatic welding process used to attach metal fastening devices (bolts, screws, rivets etc.) to metal plates or beams without drilling and tapping.* Heat supplied by an electric arc current can be adjusted and varies depending on the size of the stud and kind of metal. The duration of the arc is also adjustable on control unit.

Q. 13.34. What are the important design considerations in brazing parts ?

Ans. The following factors require due considerations in brazing points :

(*i*) Base metals;
(*ii*) Filler metals;
(*iii*) Joint configuration;
(*iv*) Service conditions like oxidation and corrosion resistance.

- Brazed joints may be either butt or lap or combination of two types. In designing joints, it should be remembered that the strength of the filler is *often less* than that of the base material. *Joint clearance* is important because it determines the *maximum joint strength* that can be developed by the particular filler metal.

Q. 13.35. Describe briefly the relative applications of A.C. and D.C. welding.

Ans.
- While D.C. welding is best suited for thinner sheel metal (below 6 mm) and also for welding non-ferrous metals, A.C. welding is used for most manual welding of 6 mm and thicker steel. As steel is the largest used structural material, A.C. welding finds maximum use, though D.C. welding has a greater variety of welding processes like GTAW and GMAW, straight polarity and reverse polarity, etc.
- Direct current straight polarity and reverse polarity welding can be used for overhead and vertical welds but A.C. welding is used for welding steel in the flat or horizontal position.

Q. 13.36. Explain briefly 'Oxyacetylene torch cutting'.

Ans. Cutting steel with a torch is an important production process. *A simple hand torch for flame cutting* differs from a welding torch. *It has several small holes for preheating flames surrounding a central hole through which pure oxygen passes. The preheating flames are exactly like the welding flames and are intended to preheat the steel before cutting.*

The principle of flame cutting *is that oxygen has affinity for iron and steel. At ordinary temperatures this action is slow, but eventually an oxide in the form of rust materializes.* As the temperature of the steel is increased this action becomes much more rapid. If the steel is heated to a red colour, about *870°C* and a jet of pure oxygen is blown on the surface, *the action is almost instantaneous and the steel is actually burnt into an iron oxide.*

- **Metal upto 760 mm can be cut by this process.**

- Flame-cutting machines which replace many machining operations where accuracy is not paramount, are widely used in the *ship-building industry, structural fabrication, maintenance work and the production of numerous items made from steel sheets and plates.*
- *Cast iron, non-ferrous alloys and high-manganese alloys are not readily cut by this process.*

HIGHLIGHTS

1. *Welding* is the method of joining metals by application of heat, without the use of solder or any other metal or alloy having a lower melting point than the metals being joined.
2. Welding processes may be broadly classified as : 1. Pressure welding; 2. Fusion welding.
3. *Seam welding* is employed on many types of pressure tanks, for oil switches, transformers, refrigerators, evaporators and condensers, aircraft tanks, paint and varnish containers etc.
4. The characteristic of a *fusion weld* is that metal being joined is actually melted and the union is produced on subsequent solidification.
5. Fusion welding is classified as :
   (*i*) Gas welding; (*ii*) Electric arc welding; (*iii*) Thermit welding.
6. Three types of welding flames are :
   (*i*) Neutral flame; (*ii*) Carburising flame; (*iii*) Oxidising flame.
7. *Arc welding* is the system in which the metal is melted by the heat of an electric arc.
8. *Thermit* welding is the method of uniting iron or steel parts by surrounding the joint with steel at a sufficient high temperature to fuse the adjacent surfaces of the parts together.
9. *Soldering* is an operation of joining two or more parts together by molten metal.
10. *Brazing* is a soldering operation using brass as the joining medium.

OBJECTIVE TYPE QUESTIONS

A. Choose the Correct Answer :

1. Upon which of the following parameters does the current intensity in arc welding depend ?
   (*a*) Stability of arc
   (*b*) Electrode diameter
   (*c*) Gap between the electrode and parent metals
   (*d*) Thickness of parent metals
   (*e*) All of the above.
2. In .... welding two non-consumable electrodes are used.
   (*a*) MIG (*b*) TIG
   (*c*) atomic hydrogen (*d*) submerged arc
   (*e*) none of the above.

3. .... brazing process is good for mass scale.
   (*a*) Furnace (*b*) Induction
   (*c*) Dip (*d*) Torch.
4. For gray cast iron, which of the following welding methods is preferable ?
   (*a*) MIG (*b*) Submerged arc
   (*c*) Gas flame (*d*) Electric arc
   (*e*) Any of above.
5. Due to which of the following reasons, *no flux* is used in atomic hydrogen welding?
   (*a*) The burning hydrogen shields the molten metal.
   (*b*) Two electrodes are coated which gradually release the flux.
   (*c*) The filler rod is coated with flux.
   (*d*) One of two electrodes is coated which releases the flux.
   (*e*) None of the above.
6. In resistance welding, between the electrodes, a current of ....voltage and .... ampere is passed.
   (*a*) high, high (*b*) high, low
   (*c*) low, low (*d*) low, high.
7. .... is the welding process in which heat is produced for welding by chemical reaction.
   (*a*) Resistance welding (*b*) Thermit welding
   (*c*) Forge welding (*d*) Gas welding
   (*e*) None of the above.
8. In case of submerged arc welding, the electrodes upto .... diameter may be used.
   (*a*) 30 mm (*b*) 20 mm
   (*c*) 15 mm (*d*) 12 mm.
9. In arc welding, arc in created between the electrode and work by
   (*a*) contact resistance (*b*) flow of voltage
   (*c*) flow of current (*d*) electrical energy.
10. Material used for coating the electrode is called
   (*a*) flux (*b*) slag
   (*c*) protective layer (*d*) deoxidiser.
11. .... is the welding process in which two pieces to be joined are overlapped and placed between two pointed electrodes.
   (*a*) Seam welding (*b*) Resistance welding
   (*c*) Projection welding (*d*) Spot welding.
12. Which of the following gases are used in Tungsten inert gas welding ?
   (*a*) Helium and neon (*b*) Hydrogen and oxygen
   (*c*) Argon and helium (*d*) Carbon dioxide and hydrogen.
13. Preheating is essential in welding
   (*a*) copper (*b*) aluminium
   (*c*) cast iron (*d*) stainless steel.

14. The temperature, in arc welding, is of the order of
(*a*) 2000°C (*b*) 3000°C
(*c*) 5500°C (*d*) 7000°C.

15. Acetylene gas is generated from
(*a*) calcium (*b*) carbon
(*c*) calcium carbonate (*d*) calcium carbide
(*e*) none of the above.

16. Striking voltage as compared to voltage during arc welding is
(*a*) less (*b*) same
(*c*) more (*d*) unpredictable.

17. Carburising flame has .... zones.
(*a*) one (*b*) two
(*c*) three (*d*) four.

18. Due to which of the following reasons distortion in welding occurs ?
(*a*) Oxidation of weld pool (*b*) Use of high voltage
(*c*) Improper clamping methods (*d*) Use of high current
(*e*) All of the above.

19. In reverse polarity welding
(*a*) work is negative and holder is earthed
(*b*) electrode holder is connected to negative and work to positive
(*c*) electrode holder is connected to positive and work to negative
(*d*) any of the above.

20. Where does maximum flame temperature occur ?
(*a*) At the inner cone (*b*) Next to inner cone
(*c*) At the tip of the flame (*d*) At the outer cone
(*e*) Any of the above.

21. In which of the following welding processes, electrode gets consumed ?
(*a*) TIG welding (*b*) Resistance welding
(*c*) Thermit welding (*d*) Arc welding
(*e*) None of the above.

22. Which of the following statements about welding is *incorrect* ?
(*a*) Increased corrosion resistance.
(*b*) Even materials like stainless steel and aluminium can be welded.
(*c*) No flux required.
(*d*) High welding speed.
(*e*) None of the above.

23. Where is half corner weld used ?
(*a*) where efficiency of the joint should be 50 percent
(*b*) where longitudinal shear is present

(*c*) where severe loading in encountered and the upper surfaces of both pieces must be in the same plane
(*d*) all of the above
(*e*) none of the above.

24. .... percent carbon steel is most weldable
(*a*) 0.15 (*b*) 0.25
(*c*) 0.35 (*d*) 0.8.

26. In which of the following metals does the phenomenon of 'weld decay' occurs ?
(*a*) Stainless steel (*b*) Cast iron
(*c*) Carbon steel (*d*) Bronze
(*e*) None of the above.

27. On which of the following principles does the 'positive pressure type torch' work ?
(*a*) Equal volume (*b*) Positive pressure
(*c*) Equal pressure (*d*) Equal flow
(*e*) None of the above.

28. Why is post cleaning necessary at brazed joint?
(*a*) To avoid corrosion (*b*) To avoid slagging
(*c*) To avoid oxidation (*d*) To avoid scaling
(*e*) All of the above.

29. Neutral flame is used to weld
(*a*) cast iron (*b*) steel
(*c*) copper (*d*) all of the above.

30. Which of the following statements about 'Projection welding' is *correct?*
(*a*) It is a multi-spot welding process.
(*b*) It is an arc welding process.
(*c*) It is a continuous spot welding process.
(*d*) It is a process used for joining round bars.
(*e*) None of the above.

31. By which of the following welding processes is gray cast iron usually welded?
(*a*) TIG welding (*b*) MIG welding
(*c*) Resistance welding (*d*) Gas welding
(*e*) None of the above.

32. Which of the following statements about copper is *correct*?
(*a*) It is very difficult to be spot welded.
(*b*) It is preferred to be welded by spot welding.
(*c*) It is easily spot welded.
(*d*) It is as good for spot welding as any other material.

33. Which of the following statements about 'Submerged arc welding' is *correct*?
(*a*) Arc is submerged is molten metal bath.
(*b*) Arc is maintained under a blanket of flux.
(*c*) There is no arc in actual.
(*d*) None of the above.

34. Due to which of the following reasons, welding of stainless steel is difficult?
(*a*) Formation of oxide film.
(*b*) Melting point of stainless steel is very high.
(*c*) Fear of cracking.
(*d*) Formation of rust.
(*e*) None of the above.

35. In arc welding the length of arc should be equal to
(*a*) half the electrode diameter (*b*) electrode diameter
(*c*) twice the electrode diameter (*d*) none of the above.

36. Compared to oxyacetylene flame temperature of oxy-hydrogen flame is
(*a*) less (*b*) same
(*c*) more (*d*) unpredictable.

37. Compared to oxidising flame, carburising flame is
(*a*) less luminous (*b*) equal luminous
(*c*) more luminous (*d*) any of the above.

38. In gas welding, more commonly used flame is
(*a*) carburising flame (*b*) neutral flame
(*c*) oridising flame (*d*) mixture of the three.

39. .... welding will be best suited for joining two stainless steel foils of thickness 0.1 mm.
(*a*) MIG (*b*) TIG
(*c*) Plasma arc (*d*) Gas.

40. Oxidising flame is used to weld metals/materials like
(*a*) copper and brass (*b*) aluminium, stainless steel, nickel etc.
(*c*) abrasive (*d*) any of the above.

41. In thermit welding, iron oxide and aluminium oxide are mixed in the proportion of
(*a*) 1 : 1 (*b*) 2 : 1
(*c*) 3 : 1 (*d*) 1 : 3.

42. Weld spatter is a
(*a*) catalyst (*b*) welding defect
(*c*) flux (*d*) none of these.

43. TIG welding is best suited for welding
(*a*) silver (*b*) mild steel
(*c*) aluminium (*d*) stainless steel.

44. Projection welding refers to
(*a*) pressure welding (*b*) TIG welding
(*c*) submerged welding (*d*) resistance welding.

45. In MIG welding, metal is transformed in the form of
(*a*) molecules (*b*) molten drops
(*c*) weld pool (*d*) a fine spray of metal.

46. In case of neutral flame, oxygen to acetylene ratio is
(*a*) 0.6 : 1.0 (*b*) 1 : 1
(*c*) 2 : 1 (*d*) 3 : 1.

47. Neutral flame has .... zones.

(*a*) two (*b*) three

(*c*) four (*d*) unpredictable.

48. In lost wax casting, tolerance is of the order of

(*a*) + 2 mm (*b*) + 0.2 mm

(*c*) + 0.02 mm (*d*) 0.005 mm.

49. In resistance welding, pressure is released

(*a*) during heating period (*b*) after the weld cools

(*c*) no pressure is applied (*d*) none of the above.

50. In which of the following welding processes the non-consumable electrode is used?

(*a*) TIG welding (*b*) LASER welding

(*c*) MIG welding (*d*) Plasma arc welding.

ANSWERS

1. (*b*)	**2.** (*c*)	**3.** (*a*)	**4.** (*a*)	**5.** (*a*)	**6.** (*d*)
7. (*b*)	**8.** (*d*)	**9.** (*d*)	**10.** (*a*)	**11.** (*d*)	**12.** (*c*)
13. (*c*)	**14.** (*c*)	**15.** (*d*)	**16.** (*c*)	**17.** (*c*)	**18.** (*c*)
19. (*c*)	**20.** (*b*)	**21.** (*d*)	**22.** (*c*)	**23.** (*e*)	**24.** (*a*)
25. (*a*)	**26.** (*a*)	**27.** (*c*)	**28.** (*a*)	**29.** (*d*)	**30.** (*a*)
31. (*d*)	**32.** (*a*)	**33.** (*b*)	**34.** (*a*)	**35.** (*b*)	**36.** (*a*)
37. (*c*)	**38.** (*b*)	**39.** (*c*)	**40.** (*a*)	**41.** (*c*)	**42.** (*b*)
43. (*c*)	**44.** (*d*)	**45.** (*d*)	**46.** (*b*)	**47.** (*a*)	**48.** (*d*)
49. (*b*)	**50.** (*a*).				

B. Fill in the blanks or say 'Yes' or 'No' :

1. .... is a process of joining two materials with the help of heat or pressure or by some other means.
2. .... is a process of joining two pieces of metal with a different fusible metal applied in a molten state.
3. A good weld is as strong as the base metal.
4. Welding does not result in residual stresses and distortion of the workpieces.
5. Welding does not permit any freedom in design.
6. Welding heat produces .... changes.
7. The characteristic of .... weld is that the metal joined is never brought to a molten stage, it is heated to a welding temperature and the actual union is brought about by application of pressure.
8. The materials like brass and aluminium can be projection welded satisfactorily.
9. When the ratio of oxygen and acetylene is equal, a .... flame is obtained.
10. In oxidising flame the ratio of oxygen to accetylene varies from about 1.2 to 1.5.
11. Heavy sections can be joined economically by gas welding.
12. The field of application of metallic arc welding includes mainly low carbon steel and the high-alloy austenitic stainless steel.
13. Atomic hydrogen welding being expensive is used mainly for high grade work on stainless steel and most non-ferrous metals.

14. .... welding is the method of uniting iron or steel parts by surrounding the joint with steel at a sufficient high temperature to fuse the adjacent surfaces of the parts together.
15. The consumable electrode in MIG process acts as the source for arc column as well as the supply for the filler material.
16. The .... arc process creates an arc column between a base metallic electrode and the workpiece.
17. Welds made by the submerged arc welding process have low strength.
18. The submerged arc process is capable of welding fairly thin gauge materials.
19. .... welding depends upon the generation of heat that is produced by passing an electric current through molten slag.
20. .... welding fusion joins metal by bombarding a specified confined area of the base metal with high velocity electrons.
21. Plasma is often considered the fourth state of matter.
22. The .... welding process is the focusing of a monochromatic light into extremely concentrated beams.
23. The laser welding process can be used to weld dissimilar metal with widely varying physical properties.
24. Hydrodynamic welding can be used to join steel to many ferrous and non-ferrous metals and alloys.
25. The .... are designated by numbers which indicate grade and by sizes of the core wire.
26. In steel welds, the .... are the most serious defects.
27. .... welding process uses only the pressure to produce the joints at room temperature and no heat is applied at any stage.
28. The welding operation for the repair of defective casting is termed as 'welding of cast steel'.
29. The brass used for making the joint in brazing is generally called ....
30. When hard soldering, the chief flux is borax.

ANSWERS

1. Welding	2. Soldering	3. Yes
4. No	5. No	6. metallurgical
7. Pressure	8. No	9. neutral
10. Yes	11. No	12. Yes
13. Yes	14. Thermit	15. Yes
16. submerged	17. No	18. Yes
19. Electro-slag	20. Electron-beam	21. Yes
22. Laser	23. Yes	24. Yes
25. electrodes	26. cracks	27. Cold
28. Yes	29. speller	30. Yes.

THEORETICAL QUESTIONS

1. Define the term 'welding' and name the various welding techniques.

2. Explain briefly the following types of flames :
   Neutral flame, Carburising flame and Oxidising flame.
3. Name and briefly explain the various equipment used in gas welding.
4. List the advantages and disadvantages of gas welding.
5. Give the comparison between A.C. and D.C. arc welding.
6. Write short notes on any three of the following :
   (*a*) Gas shielded arc welding (*b*) Submerged arc welding
   (*c*) Thermit welding (*d*) Plasma arc welding
   (*e*) Laser beam welding.
7. Explain briefly any two of the following :
   (*i*) Metallic arc welding (*ii*) Carbon arc welding
   (*iii*) Atomic hydrogen welding (*iv*) Shielded arc welding.
8. Explain briefly defects in welding.
9. Write short note on under-water welding.
10. How are welded joint tested ?
11. What do you mean by "Hard facing" ?
12. What is "Rebuilding" ?
13. What is thermit welding ?
14. Explain briefly cold welding.
15. What is the difference between shielded and unshielded arc welding processes ?
16. What are the advantages and disadvantages of D.C. and A.C. welding ?
17. Explain the inert-gas metal-arc welding ? How does it differ from other metal arc welding processes ?
18. Explain the principle of atomic hydrogen welding and the role of hydrogen in this welding.
19. What are advantages and disadvantages of spot welding processes ?
20. Differentiate between soldering and brazing.
21. Why a flux is used in soldering and brazing ?
22. What is the difference between welding, brazing and soldering processes ?
23. Explain briefly the following welding processes :
    (*i*) Friction welding (*ii*) Diffusion welding
    (*iii*) Explosive welding.
24. Give a comparison between TIG and MIG welding processes.
25. (*a*) Define *'Soldering'*. Name types of solder.
    (*b*) Explain briefly the term *'Flux'* or *'Soldering fluid'*. Enumerate the fluxes commonly used in soldering process.
26. Describe briefly the equipment used in soldering.
27. How is soldering process carried out ?
28. What are the characteristics of a good soldered joint ?
29. State the applications of soldering.
30. Explain the term 'Brazing'.
31. What is the action of a flux in brazing process. Name the chief flux used in 'Brazing'.
32. Describe step-wise the procedure of 'Brazing'.
33. Enumerate the applications of brazing.
34. Write short note on 'silver brazing'.

❑❑

14

Need for Integration

14.1. Introduction, 14.2 Integration of design and manufacturing, 14 3. Selection of process; 14.4. Process routing; 14.5. Capacity planning; 14.6. Intra work cell scheduling methods, 14.7. Dispatching; 14 8. Basic tools for integation; 14.9. Computers and microprocessors—History and development of computers—definition of a computer—characteristics of a computer—classification of computers—analog computers—digital computers—differences between analog and digital computers—block diagram of a digital computer—rating of chips—computer peripherals—storage devices—hardware, software and liveware—translators—computer languages—computer programming process for writing programs—computer elements of analog computers—microprocessor; 14.10. Computer networks for manufacturing—Introduction—computer network—local area network (LAN)—manufacturing automation protocol (MAP)—computer software; 14.11. Information technology—General aspects—data and information—information system. ***Questions with Answers—*** *Highlights—Objective Type Questions – Theoretical Questions.*

14.1. INTRODUCTION

Now-a-days the manufacturing is facing a formidable challenge in the national and international market place. The need for manufacturing high quality, low cost products is demanding major changes in the manufacturing function resulting in *facility modernisation, high level of automation and reduction in inventory and lead times.* The designer must understand and accommodate these changes to ensure that a design can be efficiently produced.

After the revolution which took place in computer technology *Computer Integrated Manufacture (CIM) is the term used to describe the complete and whole automation of the factory with all processes functioning under computer control and only digital information integrating them together.*

— CIM is the evolutionary outcome of Computer Aided Design (CAD) and drafting (CADD) and Computer Aided Manufacturing (CAM).

— CIM is required and desirable because it reduces the human component of manufacturing and thereby relieve the process of its most expensive and error prone ingredient.

14.2. INTEGRATION OF DESIGN AND MANUFACTURING

Traditionally the product design and the procedures by which the products are manufactured have been performed separately by different groups of individuals. Now-a-days, the design engineers are well versed in manufacturing procedures and processes.

Concurrent engineer attempts to integrate the product design and its related manufacturing process design.

— For each product, teams are formed that consist of design, manufacturing, quality assurance, and purchasing personnel.

— The design of the product is performing concurrently with the selection of processes, equipment, and steps that will determine how it is to be built.

— Inputs by the *quality assurance* members of the team assure that the finished product can be manufactured to predetermined levels of quality. Inputs by the *purchasing members* of the team ensure that the product will be built with parts that are available and economically procurable.

14.3. PROCESS SELECTION

Owing to the developing in *'manufacturing automation'* the number of process alternatives available to manufacturing planners have increased. *The selection of the most cost effective process is dependent upon :*

— Part geometry;

— Tolerance requirements;

— Lot size;

— Other factors.

Following are some important *'alternatives' available to process planners :*

1. Numerical Control (NC). In recent decades Numerical Control (NC) has revolutionised machining processes.

— Numerical cotrolled machine tools have the ability to machine *geometric contours* not achievable with conventional equipment. There is the additional advantages of *increased repeatability* from part to part, without variations induced by a human operator.

— Numerical control *reduces tooling cost* by eliminating the costs of sophisticated jigs and fixtures.

— Set-up costs involved with the consecutive machining of different parts are usually small.

— Numerical control is not a high-volume production process and *may be considered a form of programmable automation.*

— The purchase *costs* of NC machine tools are *higher* than conventional, manual counterparts.

— The advantages of NC machining are partially *offset* by some *overhead costs* that are created by this form of automation. In addition to higher equipment costs, other costs are incurred for the programming, check out, and storage of tapes containing the programmes for parts to be manufactured.

2. Flexible manufacturing. *"Flexible manufacturing" involves the interconnection of groups of automated machine tools by an integrated and automated material handling system.*

- *"Flexible Manufacturing Systems (FMSs)"* are used *to complete sophisticated sequences of machining operations on families of manufactured parts.* These systems often contain provisions for automated part inspection. *Hierarchical computer control* is used to schedule and route parts through the system. Such control facilitates the tracking of machine tool usage and parts produced. This information is used to schedule periodic maintenance during which cutting tools and fluids may be changed.
- FMS implementation involves significant initial costs. Product volume and projected labour savings must therefore be sufficiently high to justify these extremely high initial investment costs.

3. Robotics. During the last two decades *'Industrial robots'* have been successfully utilized in a number of manufacturing applications. Typical applications include:

— Spray painting;
— Application of coating;
— Spot welding;
— Arc welding;
— Part transport during heat-treating applications;
— Palletizing operations;
— Machine loading and unloading.

- Robots eliminate repetitive, manual labour operations. They have successfully removed human workers from hazardous working environments and from physically stressful labour tasks.
- Robots, like NC machine tools, have the requirements for the generation, checkout and storage of various movement programs.
  — Languages used are often unique to a particular robot. This information has impeded the integration of rebots into automatic manufacturing cells and systems.
- Robots have achieved only *limited use in complex assembly operations* (due to limitations) in gripper design, tactile sensing, and vision).

4. Fixed versus programmable automation. Decisions to use fixed as opposed to programmable automation alternatives are usually based on the production quality to be built.

- *"Fixed automation facilities"* are usually dedicated to the production of a single product, usually in *extremely high volumes. Fixed automation* is *characterised by extremely high costs associated with equipment procurement.* Any change in the product being manufactured results in a significant line change-over cost.
- Examples of *"programmable automated equipment"* include both *NC machine tools* and *industrial robots.* These machines are capable of producing a variety of different parts, with comparatively modest set up and programming cost. *Production output is much lower than dedicated, fixed automation equipment.*

14.4. PROCESS ROUTING

The **process routing** *specifies that sequence of manufacturing operations that is required to produce a product or sub-assembly.*

The process routing is divided into *separate steps* or *operations*. Each operation specifies the factory location or work centre in which a set of manufacturing operation is to take place. The routing contains a description of these operations along with set of machines or manufacturing facilities that are to be used.

— *Inspection operations* are also often defined as *separated routing operations.*

14.5. CAPACITY PLANNING

Capacity planning *is a method by which the master schedule is adjusted to balance the due dates of jobs or orders against the capacity of the plant and its individual work cells and facilities.*

Vollman, Berry, and Whybark describe three separate types of planning methods. The methods *differ in the amount of production data used to afford increasing levels of detail in assessing workload levels.* These methods are discussed as follows :

1. Capacity planning using overall factors (CPOF). It is a relatively simple approach that results in a "rough cut" capacity plan.

— The inputs come from the master schedule rather than from MRP tables associated with individual parts in the bill of materials.

— The workload levels are derived from performance standards or historical data for end products only.

- This method does not consider the time shifty associated with the lead times for all component parts in the end item.

2. Capacity bills :

- This method provides a more direct linkage between different end products being produced and respective capacities required by these different end items in various work centres. This method is *responsive to changes in product mix of the end items produced.*
- In order to use this approach, additional data are required. *Lot sizes* for each end product and their respective components *must be known. Set-up and run times for each lot must be defined* for each work centre in which processing is required.

3. Resource profiles. This approach further *refines* the capacity bills procedure.

— It consider the lead time requirements associated with each mode in the parts explosion diagram.

— All data for previous method are used, but are defined to occur in the specific period during which the work on a specific part or subassembly is scheduled to take place.

14.6. INTRA WORK CELL SCHEDULING METHODS

For the scheduling of jobs or orders within a given work cell a variety of methods exist. For *most rules* a notation of the form $n/m/C$ applies :

Here, n = The number of *jobs* or *orders* that are to be scheduled;

m = The number of *machines* within the work cell, and

C = The objective or criterion addressed by the developed schedule.

The *common scheduling 'objectives' are to deliver or complete the orders by the due dates required by the customer.* This is accomplished by minimizing the average or maximum lateness for a sequence of jobs or orders.

- Most early work in analyzing scheduling methodologies focussed on work cells consisting of only one or two machines and observed the following rules/procedures :
  — Shortest processing time rule
  — Due date rule
  — Slack time rule
  — Multiple machine rules
  — First come, first served and random scheduling
  — The RAND Simulations
  — Scheduling in FMS environments.

14.7. DISPATCHING

Dispatching, an important facet of the production control process, *involves the movement of parts, components, sub-assemblies, and end items so that they arrive at the appropriate work centre exactly at the time they are needed in the production process :*

In this process the following three types of materials are usually *moved.*

(*i*) The movement of a partially completed part or subassembly to the appropriate work centre.

(*ii*) The movement of raw materials or components that are to be added at a particular process operation.

(*iii*) The movement of tooling, fixtures, gauges, and inspection equipment to the work centre.

14.8. BASIC TOOLS FOR INTEGRATION

— The *"computer"* has been the *core of the information age.* Continued technological developments of the past two to three decades have propelled society into an era whereby the computer is an integral part of daily life.

— One of the most interesting developments of the information age revolution is that the computer is no longer the sale domain of the computer expert. As more users gain familiarity with the knowledge and productivity gain made possible by using computer as a tool, applications continue to grow.

— A knowledge of computer basics facilitates productivity for the computer user. For the computer systems purchaser, an understanding of computer fundamentals is essential to ensure the procurement of a unit containing appropriate hardware, software, and expansion capabilities for current and future use as well as interfaces for existing and potential data-sharing environments.

— There is a central difference between computer field and other industrial products whose growth has stabilized after reaching maturity. Rather than an end product in itself, the *computer is also a* **"tool"** *which has spurred development of new products and applications. It has become the core of a new revolution of innovations, products, and applications which will be emerging for years to come.*

- *Computers are increasingly used for doing engineering drawings and graphics work because computers allow the graphics engineer or the draughtsman to easily change the contents format, colour, size etc. of a drawing.*
- A computer is an electronic machine for processing information. The processing and storage of information inside a computer is using binary digits (0 and 1) only, and computers are called **digital computers.** Computers of other types (analogy computers) are no longer in common use.

14.9. COMPUTERS AND MICROPROCESSORS

14.9.1. History and Development of Computers

- Charles Babbage (an English Mathematician) was responsible for conceiving the concept of the Modern computer, and is called "Father of Computers".
- He designed the early computer called *"Difference Engine"* in the year 1822, with which reliable tables could be produced. In 1833 he improved upon the machine and put forth new of idea of *"Analytical Engine"* which could perform the basic arithmetic functions automatically. In this machine punched cards were used as input/output devices for basic input and output.

The concept of use of punched cards was developed further by Horman Hollerith in the year 1889.

- Leonards Torres demonstrated a *digital calculating machine* in Paris in 1920.
- In 1944 Prof. Howard Aiken (Howard University) developed Electromechanical calculators known as Mark-I. This machine could handle about a sequence of 5 arithmetic operations by using memory for previous results.
- On the basis of research done for U.S. army during the World War-II in 1946, the first electronic computer, ENiAC (Electronic Numerical Integer and Computer) was designed in 1946. This computer was about 15 meters long and 2 meter high and weighed about 50 tons. It consumed about 200 kW power. This machine did not have any facility for storing programs.
- In 1949, the *concept of stored program was adopted.*
- In 1951, was introduced the commercial version of stored program computer UNIVAC-1 (Universal Automatic Computer)—the first digital computer.

Generation of Computers :

First Generation .... Developed during the year 1951-1959.

- These computers are *"based"* on ***"Vacuum Tubes"***.
- Very slow in operation (10^3 operations/sec.)
- Big in size and unreliable.
- Short span of life.
- Frequent breakdowns.
- High power consumption and great amount of heat generation.
- Small primitive memories and no auxiliary storage.
- Limited programming capabilities.

Examples. UNIVAC-I and IMB 650.

Second generation. Developed during the years 1960-1965
- These computers are *based* on ***"transistors"***.
- Faster in operation, comparatively (10^6 operations/sec.)
- Smaller in size.
- More reliable.
- Consume less power.
- Generate less heat than vacuum tubes.
- Auxiliary memory in the form of magnetic tape was introduced.

Examples. UNIVAC 1107, IBM 7090, CDC 1604, Honeywell 800 etc.

Third generation .... Introduced during 1965-1970, also being used presently.
- These computers are based on ***"Integrated circuits"***, based on silicon technology.
- Much more smaller in size.
- More reliable.
- Faster in operation (10^9 operation/sec.)
- Less expensive.
- Employ higher capacity internal storage.
- Wide range of peripheral used.
- Make use of new concepts like *multi-programming, multi-processing, high level languages*.

Examples. IBM-360/370, Honey well 6000.

Fourth generation .... Introduced in 70s.
- These computers are based on VLSI (Very large scale integration) chips and microprocessors chips.
- Possess high processing power.
- Low maintenance.
- Faster in operation.
- High reliability.
- Very low power consumption.
- Less expensive.
- Small size.

This generation also includes the following :
— Microcomputers;
— Office automation systems;
— Distributed processing systems.

Fifth generation .... Introduced during the 1990's.
- These computers use optic fibre technology to handle *Artificial Intelligence, Expert Systems, Robotics etc.*
- Possess very high processing speeds.
- More reliable.

14.9.2. Definition of a Computer

A **computer** is a *machine that processes data according to set of instructions stored within the machine.*

- It *receives data as input, processes the data, i.e., performs arithmetic and logical operations on the same and produces output in the desired form on output device as per the instructions coded in the program.*
- The process function of the computer is *directed by the stored program, a set of codes instructions stored in the memory unit, which guides the sequence of steps to be followed during processing.*

14.9.3. Characteristics of a Computer

The following are the *characteristics* which make a computer an indispensable unit:

1. Speed
2. Consistency
3. Accuracy
4. Flexibility
5. Reliability
6. Large storage capacity
7. Automatic operation
8. Diligent
9. No emotional ego and psychological problems.

Limitations of a computer :

A computer entails the following *limitations :*

1. It does not work on itself, a set of instructions is required for its operation.
2. It cannot take decision on its own, it has to be programmed as per requirements.
3. It is not intelligent, it has to be instructed in detail for the performance of each and every task.
4. It cannot learn by experience, as human beings do.

14.9.4. Classification of Computers

The computers may be classified as follows :

1. **On the basis of the type of data :**
   (*i*) *Analog computers* (These computers process the data in analog form).
   (*ii*) *Digital computers* (These computers process the data in digital form).
2. **On the basis of the size and capacity :**
   (*i*) *Microcomputers.*
   (*ii*) *Minicomputers.*
   (*iii*) *Main frame.*
   (*iv*) *Supercomputers.*
3. **On the basis of the type of application :**
   (*i*) *Special purpose computers.*
   (*ii*) *General purpose computers.*
4. **On the basis of the number of users :**
   (*i*) *Single user computers.*
   (*ii*) *Multi-user computers.*

5. **On the basis of the number of processors :**
   (*i*) *Single processor computers.*
   (*ii*) *Multiprocessor computers.*
6. **On the basis of the type of instructions set :**
   (*i*) *Complex Instruction Set Computers (CISC).*
   (*ii*) *Reduced Instruction Set Computers (RISC).*

14.9.5. Analog Computers

- The *principle of operation of analog* computers is to *create a physical analog of mathematical problems.*
- Measure physical variables *continuously.*
- Use signals as input (which may be supplied by devices like barometers, speedometers, thermometers etc.)
- The *result* gives by an analog computer is *not very precise, accurate and consistent.*
- These computers find limited applications.

Examples. *Speedometer of a vehicle* (here speed varies continuously).

14.9.6. Digital Computers

- The digital computers *accept digits and alphabets as input.*
- Receive data in the form of discrete signals representing ON (high) or OFF (low) voltage.
- The data input can be represented as sets of O's and I's representing low and high reprectively.
- The digital computers convert data into discrete form before operating on it.
- The *most important characteristic* of a digital computer is that it is general purpose device capable of being used in a *number of different* applications. By changing the stored program, the same machine can be used to implement totally different tasks.

Example. *Digital watches.*

Digital computers may be further classified based upon : (*i*) Purpose of use (*e.g.*, General purpose, special purpose); (*ii*) Size and capabilities.

On the basis of *size and capabilities*, the digital computers are classified as :

1. Super computers.
2. Mainframe computers.
3. Medium sized computers.
4. Minicomputers.
5. Microcomputers.

1. Super computers :

- These computers are the fastest (speed of calculations upto 1.2 billion instructions per second) and have very high processing speeds.
- They are very large in size and most powerful and constliest.
- Their fields of applications include processing weather data, geological data, genetic engineering etc.
- Word length : 64 bits and more.
- These computers can receive input from more than 1000 individual work stations.

Example. PARAM (a super computer developed in India).

2. Main frame computers :

- These are large scale general purpose computer systems.
- Possess large storage capacities in several million words.
- Secondary storage directly accessible—of the order of several billion words.
- Can support a large number of terminals (upto 100 or more)
- Faster in operation (100 million instructions/sec. approx).
- *Accept all types of high level languages.*
- Word length—16 or 32 or 64 bits.

3. Medium sized computes :

- Mini verisons of mainframe computers
- They have smaller power than mainframes.
- Processing speeds relatively high with support for about 200 remote systems.

4. Minicomputers :

- These are general computer systems.
- Reduced storage capacity and performance (as compared to main frame).
- CPU speed—few million instructions/sec.
- Word length—16 or 32 bits.
- Can accept all types of high level languages.
- Can support upto about 20 terminals.

Note : In view of fast development in electronics it is difficult to draw a line of demarcation between small main frame computers and large minicomputers.

5. Microcomputers :

- These are small size computers *utilising microprocessors*. These are popularly known as personal computer (P.C.)
- CUP is usually contained on one chip.
- Possess low storage capacity (maximum being 256 K words.)
- Slow in operation (10^5 instructions/sec.)
- Usually provided with *video display unit, floppy drive and printer.* Some microcomputers can support hard disc also.
- Maximum word length is 16 bits; however most of these use 8-bit words.
- Commonly used language—BASIC. However these computers can also accept other high level languages, *viz.* PASCAL, FORTRAN etc.

Note : **A single chip microcomputer* consists of a single chip on which the central processing unit, input/output and memory units are integrated. This is used for *industrial applications* and also in *product calculators.*

**Its advantage is the reduction in cost and size, increase in performance and reliability.*

14.9.7. Differences between Analog and Digital Computers

The differences between analog and digital computes are given in the Table 14.1.

TABLE 14.1

Differences between Analog and Digital Computers

S.No.	*Digital computer*	*Analog computer*
1.	It performs calculations by counting and thus counts directly. It is the most *versatile machine.*	It processes work electronically by *analogy.* It does not produce number but produces its results *in the form of graph.* It is *more efficient in continuous calculations.*
2.	It operates on inputs which are on-off type (being digits 0 or 1) and its output is in the form of off signals.	It accepts variable electrical signals (analog values) as inputs, and its output is also in the form of analog electrical signals.
3.	It is based on counting operation.	It operates by measuring analog signals.

These days *digital computers are being widely used.*

A hybrid computer is combination of both analog and digital computes. It is used for *simulation applications.*

14.9.8. Block Diagram of a Digital Computer

Fig. 14.1 shows a block diagram of a typical digital computer.

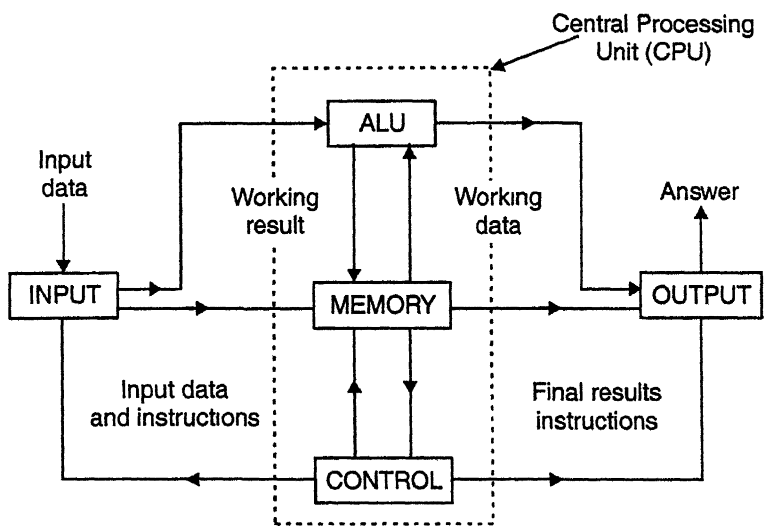


Fig. 14.1. Block diagram of a digital computer

The following are the *five basic elements* of a computer system :

1. Input :

- The data and instructions are first recorded on a machine readable medium, like punched card, and then fed into the computer via a device that codes them in a manner which is suited to conversion into electrical pulses before entering memory.
- The input supplies data to the computer in digital (binary) form.

2. Memory :

- The memory section within the computer is where data are stored or memorized.
- Problems to be solved, inputs for the problem, a program of instruction, working data, intermediate results and final results are *types of memory data.*
- The memory section holds data between high speed computer operation and slower input and output devices.

3. Arithmetic Logic Unit (ALU) :

- ALU performs necessary arithmetical operations on the data and ensures that instructions are obeyed.
- It also performs *logical operations.*
- The ALU combined with control unit is called *central processing unit.*

4. Control Unit :

- It fetches instructions from main memory, interprets them and issues the necessary signals to the components making up the system.
- It issues commands for all hardware operations necessary in obeying instructions.

5. Output :

- The output is the path for data out of the computer and may include devices for reading out answers.

14.9.9. Rating of Chips

Chips are rated in terms of their *capacity* and *speed.*

- *Capacity* of a chip refers to the amount of *kilo-bites it can store.*
- *Chip speed* refers to the rate at which the microprocessor can write to the chip. It is usually measured in nano-seconds (ns). As the chip speed increases, its cost goes up.

14.9.10. Computer Peripherals

A **peripheral** *is any device commonly used with a CPU of a computer for input or output of information or for memory functionally separate from the CPU and electronically detachable.*

Input Devices :

1. Keyboard :

- It is the most common and simplest input device.
- It is merely a collection of momentary switches. The outputs of the key switches are fed to electronic circuitry known as *keyboard encodes* which convert them into binary coded values. The values are then fed into the computer which interprets the key which was pressed. Thus the function of the key changes with the type of work we are doing.

2. Mouse :

- It is a pointing device and its size is about the size of palm.
- It is hand-held device that *controls a pointer on the screen.*
- It rolls on a small ball. A mouse has one or more buttons on the top. When the user moves the mouse over a flat surface, the screen cursor moves in the direction of the mouse movement.

3. Digitizer (or Graphic tablet) :

- It is similar to light pen.
- It consists of a glass plate on which digitizing tablet is moved.
- It is used for fine drawing works and for image manipulation application such as Autocad.

4. Optical Mark Reader (OMR) :

- OMR is being used for reading the answer sheet by means of light. It can read upto 150 documents per minute; when on-line with respect to the computer system, can read upto 2000 documents per minute.
- OMR can also be used for such applications as *order writing payroll, inventory control, insurance, questionnaires etc.*

5. Magnetic Ink Character Reader (MICR) :

- MICR uses a special ink to print character. These character can be decoded by special magnetic devices.
- This system is employed *by banks for processing cheques.*

6. Scanner :

- It is used for getting existing graphical images (like photographs, mats, etc.) into computer.
- Once the graphical image is scanned and brought into the computer user can include them into documents or can edit them.

7. Light pen :

- It consists of a pen like device and photoelectric cell.
- It is used to draw pictures on the screen.
- When light pen is in contact with screen, the electron beam activates the photoelectric cell which in turn sends signals into the computer ultimately a mark is made on the screen where light pen contacted the screen.

8. Joy-stick :

- It is screen-pointing device.
- A stick is present with a button at the top. It can be held in the hand and bent in any one of the four directions. As the stick is moved, the action on the screen changes in the appropriate direction.
- A joy-stick is *widely used for playing computer games.*

9. Touch screen :

- The touch screen technique involves beam and ultrasonic waves.
- By using touch screen we can issue command to the computer by touching the screen.
- Limited amount of data can be entered via a terminal or a micro-computer that has a touch screen.

10. Compact Disk Read Only Memory (CDROM) :

- It is a 120 mm diameter disc with a polycarbonate subtrate, a reflective metalised layer on one side, with a protective lacquer finish.
- Here a laser beam is used to burn a small hole or pit which represent binary '1'. The absence of pit represents '0'. In this way digital information is stored on the disc in large quantities (in Giga Bytes).

11. Voice Recognition System or Voice Synthesizer :

- Voice recognition techniques, along with several other techniques, are used to convert the voice signals to appropriate words and devoice the correct meanings of words. There has been a limited success in this area and these days devices are available commercially to recognize and interpret human voices.

Output Devices :

1. Printer :

- A printer is *device that produces copies of text and graphics on paper.*
- The printers are classified/categorised as follows :

A. Impact printers :

(*i*) Solid Font
(*ii*) Dot Matrix.

B. Non-impact printers :

(*i*) Thermal printer
(*ii*) Inkjet printer
(*iii*) Laser printer
(*iv*) Electrographic printer
(*v*) Electrostatic printer.

2. Plotters :

- Plotters are those devices which *reproduce drawings using pens that are attached to movable arms.*
- Plotting in different colours is possible.

3. Monitors or Visual Display Unit (VDU) :

- A monitor is a television like device, which is used to display information, output and input data.
- It consists of a cathade ray tube (CRT), on which the information is displayed. When the user processes any key on the keyboard, the keyboard encoder generates code of that key which is depressed. This code is then fed to the computer; from there VDU system takes that code and displays it on the screen.

14.9.11. Storage Devices

The memory devices in a memory unit (which stores the data, instructions and intermediate results) may be of the following types :

1. Internal storage device .... also known as *main or primary* storage device.

The primary storage devices currently in use in computers are :

(*i*) Magnetic core memory device.
(*ii*) Thin film memory device.
(*iii*) Thin rod memory device.
(*iv*) Plated wire memory device.

2. Auxiliary storage device :

The popular *secondary memory devices* are :

(*i*) Magnetic tape drive.
(*ii*) Magnetic disk drive.
(*iii*) Magnetic drum.
(*iv*) Floppy disk.
(*v*) Winchester disk.

Method of Input to Backing Stores :

The following methods are generally used :

(*i*) Key-to-tape (*ii*) Key-to-cassette/cartridge

(*iii*) Key-to-disk/diskette

Memory. The memory is used to store information/data so that is can be retrieved whenever required. There are mainly two types of memories :

1. Primary memory.
2. Secondary memory.

1. Primary memory :

- It is also known as core memory, main memory, RAM (Random Access Memory).
- It is constructed using purely semiconductor devices, data is stored in the form of voltages.
- It is a volatile memory where as ROM (Read Only Memories) are non-volatile memories.

2. Secondary memory :

- Secondary memory, also known as *auxiliary memory*, is used to store large volumes of data.
- Data is stored in the form of magnetic energy and can be stored (in the secondary memory) for large periods.

Difference between Read Only Memory (ROM) and Random Access Memory (RAM).

ROM :

- As the implies ROM is a memory unit that performs the read operation only; it *does not have a write capability*. This implies that the *binary information stored in a ROM is made permanent during the hardware production of the unit and cannot be altered by writing different words into it.* Whereas a *RAM is a general-purpose device whose contents can be altered during the computational process.*
- ROM is a type of memory chip that we can read only and we cannot write on it.
- ROM provides permanent storage for program instructions.
- The most important ROM chip in any computer is ROM BIOS (Basic Input/Output System).
- ROM is most oftenly used in microprocessors that always execute the same program such as BOOT STRAP LOADER.

Disadvantages of ROM :

(*i*) A ROM is prepared by the manufacturer and cannot be altered once the chip has been made.

(*ii*) It is slow.

The *ROM memory* may be **classified** as follows :

(*i*) *Programmable Read Only Memory (PROM)*. Here, the information can be altered, but *not as easily as in the ordinary memory*. Once the operations to be performed have been written into a PROM chip, they are permanent and cannot be changed.

(*ii*) *Erasable Programmable Read Only Memory (EPROM)*. This type of ROM can be erased and programmed with the help of special equipment. It has a window at its top, which if exposed to ultravoilet light, allows data to be erased.

(*iii*) *Electrically Erasable Programmable ROM (EEPROM)*. In order to erase and reprogramme this type of ROM, it is requıred to be removed from the socket.

(*iv*) *Flash EPROM*. It is the latest type of ROM. A manufacturer can make changes to the flash EPROM white it remian in the PC, by running a special program.

RAM :

- This memory is so named since memory registers can be accessed for information transfer as required.
- RAM chip is made with Metal Oxide Semiconductor (MOS).
- RAM chıps may be classified as :

  (*i*) *Dynamic RAM :*

  It provides volatıle storage (*i.e.*, the data stored is lost in the event of a power failure).

  (*ii*) *Static RAM :*

  These chips are more complicate and take up more space for a given storage capacity than dynamic RMA chips. These chips are also volatile in nature but as long as they are supplied with power, they need not require special regenerator circuits to retain the stored data.
- *Static RAM chips are thus used in specialised applications while Dynamic RAM chips are used in the primary locations.*
- Owing to the volatile nature of these storage elements, a back up *Uninterrupted Power Systems (UPS) is often installed along with larger computer systems.*

14.9.12. Hardware, Software and Liveware

Hardware :

The set of *physical components, modules and peripherals comprising a computer system* is called *Hardware.*

Apart from wires and nut bolts, the major hardware components are :

(*i*) Input-output devices
(*ii*) Control unit
(*iii*) Memory
(*iv*) ALU.

Software :

The software is a *set of programs required for data processing activities of the computer*. In other words, the program written in any one of the computer languages, is called *software.*

System software includes the following :

(*i*) Operating systems.
(*ii*) Language processors (assemblers, compilers, interpreters).
(*iii*) Utility program.
(*iv*) Subroutine program.

Livware :

All persons concerned with computers, *i.e.*, compiler, programmer, etc. are called *liveware.*

14.9.13. Translators

A **translator** is *a software program which converts statements written in one language into another, e.g.*, converting assembly language to machine code etc. The assembly language program is called *'source program'* and the machine code program is called *'object program'*.

There are three types of *translators* :

1. Assembler.
2. Compiler.
3. Interpreter.

14.9.14. Computer Languages

1. Machine language. It is a programming language in which the instructions are in a form which allows the computer to perform them immediately, without any further translation. Instructions in machine language are *in the form of a binary code*, also called machine code and are known as machine *instructions.*

2. Low level language. Low level languages are machine oriented languages in which each instruction corresponds or resembles a machine instruction. The low level language must be translated into machine language before use.

3. High level language. The development of high level language was intended to overcome main limitations of low level language. The high level languages have an extensive vocabulary of word, symbols and sentences.

Difference types of high level languages are :

(*i*) *Commercial language....* The most well known commercial language is COBOL (Commercial Business Oriented Languages)

(*ii*) *Scientific language .....* The most well-known languages among this group are:
  (*a*) ALGOL (Arithmetic Oriented Language)
  (*b*) FORTRAN (Formula Translation)
  (*c*) BASIC (Beginner All Purpose Symbolic Instruction Code)

(*iii*) *Special purpose language.*

(*iv*) *Command language.*

(*v*) *Multipurpose language.*

14.9.15. Computer Programming Process for Writing Programs

The complete computer programming process followed by programmer for writing comprises the following **steps :**

1. Analysis
2. Flow charting
3. Coding
4. Debugging
5. Documentation
6. Production.

14.9.16. Computer Elements of Analog Computers

1. *Attenuators .....* are used to multiply a variable quantity by a constant.
2. *Summing amplifiers ....* are used to add or substract variables as required.

3. *Servo multipliers* .... are used to multiply two variables.
4. *Function generators* .... are used to simulate the arbitrary behaviour of variables.
5. *Integrating amplifiers* ...... are used to integrate a variable with respect to time.

14.9.17. Microprocessors

14.9.17.1. General aspects

- The **microprocessor** *is a semiconductor device consisting of electronic logic circuits manufactured by using either a large-scale (LSI) or very-large scale integration (VLSI) technique.*
- The microprocessor is *capable of performing computing functions and making decisions to change the sequence of program execution.* In large computers, the central processing unit (CPU) performs these computing functions and it is implemented on one or more circuit boards.
- The microprocessor is in many ways *similar* to the CPU, however, the microprocessor includes all the *logic circuitry* (including the control unit) on one chip.

The microprocessor consists of the following three *segments* (refer Fig. 14.2)

1. Arithmetic/Logic Unit (ALU). In this area of the microprocessor, computing functions are performed on data. The ALU performs arithmetic operations such as addition and subtraction, and logic operations such as AND, OR and exclusive OR. Results are stored either in registers or in memory or sent to output devices.

2. Register Unit. This area of the microprocessor consists of various registers. The registers are used primarily to store data temporarily during the execution of a program. Some of the registers are accessible to the user through instructions.

3. Control Unit. The control unit provides the necessary timing and control signals to all the operations in the microcomputer. It controls the flow of data between the microprocessor and peripherals including memory.

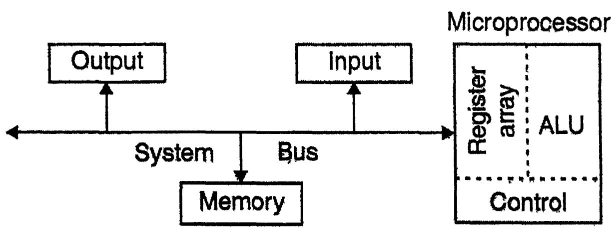


Fig. 14.2. Block diagram of microcomputer.

In short a microprocessor performs the following *functions* :
- Communicates with all peripherals (memory and I/O) using system.
- Controls timing of information flow.
- Performs the computing tasks specified in a programme.

14.9.17.2. Characteristics of Microprocessor

In nearly every type of design, with any complexity at all, microprocessors have potential for *drastically reducing component count and shortening design time.* In fact a microprocessor is considered to represent long-awaited next generation of digital building blocks, and that microprocessor will provide the best single approach to the system-level digital integrated circuit.

Some of the characteristics of a microprocessor are listed below :

1. It *handles shorter words than other computers*, usually from 4 to as many as 16 bits.
2. It consists of *integrated circuits* from 1 to 30 in number.
3. It contains arithmetic logic unit (ALU), registers, control, random access memory (RAM), data bases and read only memory (ROM) with programmes.

14.9.17.3. Important Features

The *important features* of the microprocessors are :

1. Low cost
2. Small size
3. Low power consumption
4. Versatile (The versatility of a microprocessor results from its 'stored programme' mode of operation).
5. Extremely reliable.

Note. Probably the term 'micro' in the name of the device can be contributed to its *low cost, small size and low power consumption.* The processing capability of a microprocessor should hot, however, be underestimated Currently available 32-bit microprocessors have a processing power similar to that of the mainframe computer of a few years ago. Even the early 8-bit microprocessors are powerful enough to perform several applications.

14.9.17.4. Uses of Microprocessors in Instrumentation

The processing power of the 8-bit microprocessors is more than adequate to satisfy the requirements of most of the *instrumentation applications*. By making an instrument microprocessor-based, it can be made *intelligent by incorporating new features like programmability,* which cannot be provided in its hard-wired counterpart.

Some important *uses* of microprocessors in instrumentation area are listed below :

1. Frequency meters
2. Function generators
3. Frequency synthesizers
4. Spectrum synthesizers
5. **Intelligent instruments CRT terminals**
6. Digital millimeters
7. Oscilloscopes
8. Counters
9. **Process control**
   — Instrumentation
   — Monitoring and control
   — Data acquasition
   — Logging and processing

10. **Medical Electronics**
    — Patient-monitoring in intensive care unit
    — Pathological analysis
    — Measurement of parameters like blood pressure and temperature.

Under this heading the following instruments/machines are included :

(*i*) Microprocessor based medical instrument
(*ii*) Microprocessor based ECG machines
(*iii*) Microprocessor based EEG machines etc.

Other Applications of Microprocessors :

(*i*) High level language computers
(*ii*) Replacing hard-wired logic by a microprocessor
(*iii*) Control of automation and continuous processes
(*iv*) Computer peripheral controllers
(*v*) Home entertainment and games.

14.9.18. Computer Terms

Abort. To terminate the execution of a program and to control the operating system.

ALU (Arithmetic and logic unit). The portion of the CPU that performs arithmetic and logical operations.

Access. To locate desired data.

Accummulator. A register, or set of registers in the central processor used for temporarily storing the numerical result on an operation performed by the ALU.

Adder. A *logic device* that performs the arithmetic addition of two binary numbers.

ALGOL (Algorithmic language). Arithmetic language by which numerical procedures may be presented to the computer in a blended form.

Assembly. The process of translating a program written in symbolic code into its equivalent machine code; the time during which this process occurs is called *assembly time.*

ASCII. An eight level (7 bits + 1 parity bit) code from American Standard Code for Information. In it, the letters, numbers and symbols are coded as 7 binary characters, 8th bit being used for parity check. $2^7 = 128$ character can be represented by this code.

Bar Code. A pattern of printed lines in binary coding that can be read into the computer by light pen scanning.

BASIC. Beginner's All Purpose Symbolic Instruction Code—a programming language that is easy to learn and widely used as first programming language taught in schools and as the principal language in many minicomputers and microcomputers. Although it is simple to use, it contains many advanced features for handling mathematical formulae and character strings.

BCD (Binary Code Decimal) Numbers. It is a code in which notation is preserved and each decimal digit is coded in binary, form, using 4 bits (called a nibble) for each successive digit.

Binary. A numbering system using only the digits 0 and 1. Also called "base-2".

Bit. An acronym for Binary Digit. It is the simplest possible information element. It is an entity which may have one of the two states, *i.e.*, on or off represented by 1 or 0. It is the *smallest* unit of information in the binary numbering system.

Boolean Algebra. An algebra defining the rules for manipulating variables in symbolic logic. Boolean algebra was developed as a method for expressing logical concepts in a mathematical form and uses such logical operators as AND, OR, NOR and IF-THEN.

Bootstrap. When power supply to a computer using main memory as semiconductor memory fails, all its memory is washed off. In order to restart, *i.e.*, enable it to work, it has to be programmed to accept instructions. This process is called *bootstrap.*

Bubble memory. Latest art in a memory device. When an external field is applied to a ferromagnetic specimen, the domains in which magnetisations are antiparallel get converted into cylindrical domains known as *bubble*. This size of the *bubble* is of the order of 1 to 100 microns.

Bug. Refers to fault resulting from a programming error. Sometimes it also refers to faults resulting from hardware design or construction errors.

Bus :

- It is a digital highway or an electrical channel along which data can be sent and received.
- It interconnects various elements of a computer and conveys data, addresses, instructions and control signals between the registers, arithmetic and logic unit (ALU), control unit and memory.
- There may be separate buses for data and instruction or a common bus. These can be unidirectional or bi-directional.

Byte :

- A group of consecutive bits forming a unit of storage in the computer and used to represent one alphanumeric character.
- It usually consists of 8-bits but may contain more or fewer bits depending on the model of computer.

CAD/CAM :

- Acronym for Computer-Aided Design/Computer-Aided Manufacturing.
- A computer system used in engineering for such projects as designing parts and machinery, precisely calculating parts specifications and generating complex wiring diagrams.

Call. A transfer of program control to a subroutine.

Capacity. The amount of information that all or a part of a computer system, such as main memory or a disk, pack, can store. For example; the capacity of a computer's main memory could be 512 K of information (524, 288 characters)

Character. An alphabetic letter, digit or special symbol.

Chip :

- It is a tiny piece of semiconductor material on which microscopic electronic components (*e.g.*, resistors, capacitors, diodes etc.) are all created by photoetching at the same time in one chip of silicon to form one or more circuits.
- It is usually a few millimeter square in size and is encapsuled in rectangular plastic or ceramic package, usually 20 mm wide 400 mm long.
- After connection leads and a core are added to the chip, it is called an IC (Integrated Circuit).

CMOS (Complementary Metal Oxide Semiconductor)

- This is an integrated circuit family, having high threshold logic and a technology which consumes very low power compared to other semiconductor technologies.
- It has moderate speed and high integrated device density.

COBOL :

- Acronym for Common Business Oriented Language.
- A high level programming language capable of performing all the necessary calculations most-often used in *business.*

Compiler :

- A program that translates a source program written in a high level language into its equivalent machine language.
- The output program from a compiler is called an *Object Program.*

Computer :

- A machine capable of receiving, storing, manipulating and yielding information such as numbers, words, pictures.
- Unless qualified, the word computer means electronic digital computer.

Computer Graphics. The use of a computer to produce pictorial representations or relationships such as charts and two-or-three dimensional images, by means of dots, lines, curves etc.

Computer Program. A series of instructions or statements, in a form acceptable to a computer prepared in order to achieve a certain result.

Control Unit. It generates control signals (switching signals to control the sequencing of data flows and ALU operations).

Controller. A device (*e.g.*, a register) used to represent the number of occurrences of an event.

CPU :

- Abbreviation for Central Processing Unit the portion of a computer composed of the ALU and the Control Unit.
- It is where instructions are fetched, decoded and executed and the overall activity of the computer is controlled.

Crash. A term used when the computer breaks down at the time of programming.

Data :

- Characters grouped together in specific patterns, to which meaning is assigned.
- Commonly used to designate the numbers, facts, concepts, or the like to be processed by a program although any information input to a computer system is considered data.

Data base. A collection of logically related data elements that may be structured in various ways to meet the multiple processing and retrieval needs of individuals/organisation.

Debug. To trace and correct errors in programming code of hardware malfunctions in a computer system.

Decode. To interpret a code.

Documentation. A collection of written description and procedures that provide information and distance about a program or about all or part of a computer system so that it can be properly used and maintained.

DOS. Acronym for Disk Operating System.

DP. Abbreviation for Data Processing.

Encode. To convert data into a code.

Feedback. Data produced as output by a program and used as input to another phase in the same program so as to modify or correct the factors that have produced the output.

File :

- A collection of logically related records dealt with as a unit.
- It is usually referenced by a symbolic name.

Floppy Disk. Auxiliary memory storage device consisting of magnetic film coated on the flat plastic substrate.

Flow Chart :

- A graphical representation of the processing steps performed or sequence of logic operations implemented in hardware, software, firmware or manual procedures.
- It is chart illustrating the logic sequence of events that must be performed to attain a predetermined aim.

Format. The arrangement and location of data items within a large unit of storage.

FORTRAN. Acronym for FORmula TRANslation, a scientific programming language used to perform mathematical computation.

Gate :

- A circuit that has one or more input signals and produces a signal output of binary 1 or 0, depending on the type of logic built into the circuit.
- The relationship of input and output logic gates is generally described in a *"truth table"*.

Hardware. The physical equipment and components in a computer system.

Hybrid computer :

- The computer that is a combination of an analog and digital computer linked together by an interface system for converting analog data or vice-versa.
- Used in scientific research and other such specialized applications.

Input. Data fed to computer and process of feeding it.

Inverter :

- A gate with only one input and one output.
- The output is always the complement of the input.
- Also known as a NOT gate.

Karnaugh Map. A graphical display of the fundamental products in a truth table.

Language. A means of conveying information (data) between people and machines.

LIFO. Acronym for Last In-First Out.

Latch. The simplest type of flip-flop, consisting of two cross coupled NAND or NOR latches.

LED (Light Emitting Diode) :

- A semiconductor diode, the junction of which emits light when energised [passing a current in the forward (junction ON) direction].
- Used in the construction of display indicators.

Logic Circuit. A circuit whose input and output signals are two states, either high or low voltage.

Loop. A series of instructions which are executed interactively.

Machine Language. The language with which a computer works directly.

Master file :

- A file containing relatively permanent data.
- This file is often updated by records in a transaction file.

Microcomputer :

- A small, low cost computer containing a microprocessor.
- Used for a wide variety of purposes, as in a small department within large businesses, and in home, as for household management, video games etc.

Microprocessor :

- A chip that contains the ALU, SCRATCH PAD MEMORY, and CONTROL UNIT in a microcomputer.

Minicomputer. A computer, size wise, in between a micro and mainframe types.

Modular Programming. Technique of working programs in modules.

MOSFET. Metal Oxide Semiconductor Field Effect Transistor.

Parity. The concept of parity is a check on the accuracy of data.

PASCAL. A popular high-level language that facilitates the use of structured programming techniques.

Personal Computer (P.C.). A relatively low-cast portable microcomputer, generally sold with software packages and useful and word processing, maintaining a budget, storing mailing lists, playing computer games etc.

Program. A list of instructions defining the sequential activities or operations to be performed by a computer to solve a problem.

Programming. Giving instructions to a computer before it begins to work.

RAM (Random Access Memory). A type of memory chip that can be read but cannot be written on or altered.

Word Processor :

- An automated, computerized system incorporating variously an electronic type writer, CRT terminal, memory, printer and the like.
- It is used to prepare, edit, store, transmit, or duplicate letters, reports, records etc. ..., as for business some programs now have spelling and syllabification varifiers.

14.10. COMPUTER NETWORKS FOR MANUFACTURING

14.10.1. Introduction

With the increase of technological developments the use and capabilities of computers, the need likewise occurred for communications from *peripherals* to the computer and between computers themselves. Advances in the telecommunications industry have kept pace and interfaced with technology enhancements in the computer field, making the two industries very compatible. Early computer networking involved connecting terminals to nearby host computers. The deployment of modem and other communication devices which enabled the conversion of digital-based computer

codes to analog signals carried over telephone lines brought computer capabilities closer to the user. Networks linking computers and peripherals over great distances are referred to as *wide-area networks*.

14.10.2. Computer Network

- **A Computer Network** *is a number of computers interconnected by one or more transmission paths*. The transmission path is usually the *telephone line*.
- The *main aim* of network is *"the transfer and exchange of data between the computers and terminals."*

Advantages of networks. Following are the *advantages of networks* .

1. It is possible to manufacture high quality products at relatively low cost.

2. The networking of computers permits the sharing of resources.

3. Network systems make it possible for companies to accomplish the synthesis, analysis, evaluation and documentation of the design in much less time than with manual methods.

4. The use of networking allows a 'very flexible working environment'.

5. Now-a-days, modern organisations are widely dispersed with offices located in diverse parts of a country and the world. Many of the computers and terminals at the sites need to exchange information and data often daily. *A network provides means to exchange data among these computers and to make programs and data available to the people of the enterprise.*

14.10.3. Local Area Network (LAN)

14.10.3.1. General aspects

Local Area Networking (LAN) *provides short range interconnectivity between the devices in the network, normally within one site.* Data transmission on a local area network is *typically in digital form and does not require conversion.*

In a ***factory*** the computers communicate with each other by means of LAN. A local area network is a non public communication system which permits the various devices connected to the network to communicate with each other over distances from several feet to several metres. The factory devices that can be attached to the network include :

— Computers;
— Programmable controller;
— CNC machine;
— Robots;
— Data collection devices;
— Bar code readers;
— Vision systems etc.

- Major companies with branches usually have the need for both wide area and local networking. Networking has enabled companies to choose between centralised and decentralised computer systems. A decentralised system, known as a *"Distributed Data Processing* (DDP) system, utilises several linked computers to facilitate data sharing.

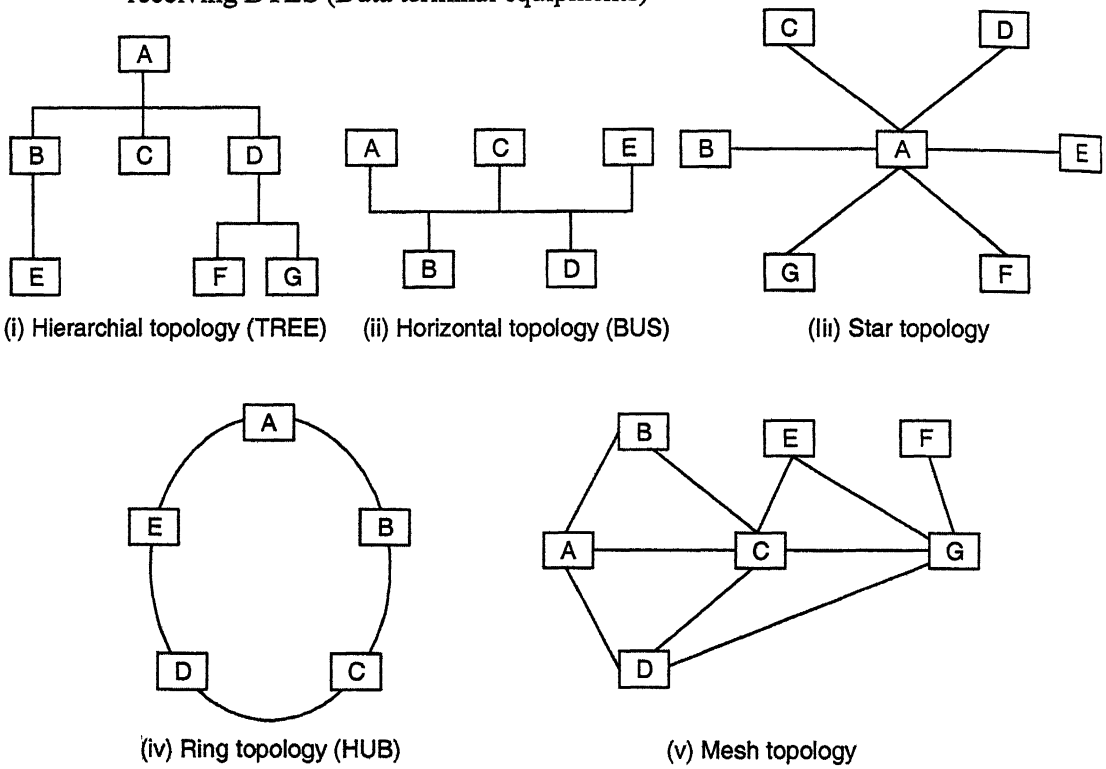
— In a *DDP system,* multiple computers perform specialized tasks and communicate with other CPUs and/or devices as needed.
— In a *centralised system*, user terminals connect to the main frame at the headquarters.

14.10.3.2. Network Topologies

A *network configuration is called a* **network topology**. A network topology is the *shape or the physical connectivity of the network.*

The network design has the following three major goals when establishing the topology of a network :

(*i*) To give the end user the best possible response time and throughout.
(*ii*) To provide maximum possible reliability to assume proper receipt of the all traffic (alternate routing).
(*iii*) To route the traffic across the least cost path within the network between the sending and receiving DTES (Data terminal equipments)



(i) Hierarchial topology (TREE) (ii) Horizontal topology (BUS) (iii) Star topology

(iv) Ring topology (HUB) (v) Mesh topology

Fig. 14.3. Network topologies.

The more common network topologies, shown in Fig. 14.3, are :

(*i*) Hierarchial topology (TREE)
(*ii*) Horizontal topology (BUS)
(*iii*) Star topology
(*iv*) Ring topology (HUB)
(*v*) Mesh topology.

For a *factory local area network the "bus network" is the most appropriate* due to the following *reasons* :

(*i*) The bus network is generally easıer to maintain and repair than the star or ring configuration.

(*ii*) The main transmission line of the bus network can be laid out ın a pattern that corresponds closely to the layout of machine in the factory, thus facilıtatıng ınstallatıons of the communication systems.

Example. The product flow line layout.

(*iii*) Machines and other devices in the plant are often being rearranged to match the changing production requirements. On bus network each device can be connected to the maın transmissions bus without major disruptions to the rest of the network.

- The major differences between local area and wide-area networks are the communıcatıon medıum and subsequent need to use or not to use the signal conversıon equıpments.

Transmission line. The *"transmission line" is the message and data carrying medium that constitutes the physical distribution elements of the network.* Followıng are the requırements of the transmission data for factory networks :

(*i*) They must be *inexpensive* to install servıce and alter.

(*ii*) They must be capable of a high data transmıssıon capacity.

(*iii*) They must be *unaffected by electrical noise in the environment.*

- *The data transmission capacity is characterised by a term called "bandwidth". Because of the need for multiple simultaneous data transmission in factory networks, "Broad band" transmission is preferred.*

In local area network the followıng three types of transmission medıa are used :

(*i*) Coaxial cable

(*ii*) Twisted pan wire

(*iii*) Fıbre optic lines.

— Coaxial cable is used in the vast *majority of* LASNs.

— Twisted copper line, fibre-optic, microwave, and statellite connections are used in *wide area networks.*

Data transmission rate. In communication network, the *"transmission rate"* ıs *the rate at which data and messages can be transferred among computers and computers controlled devices connected to the network. "Band rate"* and *"bit rate"* are the two units of measure used to ındıcate the data transmission rate.

14.10.4. Manufacturing Automation Protocol (MAP)

In implementing the networks, one of the major problems encountered is that, the various computers and computer based devices in the structure are not always compatible in terms of their ability to communicate with each other. The procedure used to *rectify* the above mentioned problem is known as *"communication protocols".* **MAP** *is a set of protocol standard designed for use in a factory local area network.*

Automation protocol uses :

— A bus network configuration;

— Broad band transmission;

— A token passing access scheme;

— A data transmission rate of 10 megabits per second.

- **MAP** is based on specification defined by the International Standards Organisation (ISD) called the Open System Interconnected (OSI) reference model.

14.10.5. Computer Software

The collection of programs, together with the data used by the programs and documentation describing them, is known as **Computer software**. Data on the computer are organised into files which consist of various records, typically organised.

Software is typically categorised into two basic types. *"Systems software"* and *"Applications software"*.

Systems software. *It is the collection of programs that coordinate the various components of the computer system.* The basic language of the computer is machine language, where the coding is binary digits. Since machine language is complex, intermediate assembler language and high-level programming languages such as COBOL, FORTRAN, PASCAL, BASIC, C, LISP, and host of other have been developed. *Programs are characterised by a definite set of procedures which instruct the computer how to proceed.*

To enable the computer to process a program written in *higher-level language, it must be converted to machine language.*

Operating systems. It is the main program that allocates the system resources and manages and controls the computer's activities.

The operating system *schedules and performs input/output, allocates space and resources, provides monitoring and security functions, and governs the execution and operation for the various system programs and applications.*

- The system's overall performance depends on the operating systems's ability to manage various functions efficiently, as well as on the hardware's capabilities.

Software tools. Another type of software is a group of programs referred to as *software tools.* The most frequently utilised software tools are :

— Database mangers;
— Spreadsheet packages;
— Graphics packages;
— Word-processing systems.

Applications programms. Applications programms are the *programs which are written in a programming language to solve a specific problem.* Although hardware and systems software provide the major access point to problem solving by computer, neither would be of much use without applications programs. The capabilities of modern computers have created a lost of new applications for virtually every profession and industry. *Typically used industrial engineering applications are* :

— Computer-aided design (CAD);
— Computer-aided manufacturing (CAM);
— Computer-aided process planning (CAPP);
— Cost estimating;
— Routing and scheduling;

- Time standards;
- Machine processes;
- Material resource planning (MRP);
- Plant layout;
- Quality control.

- Computer-integrated manufacturing (CIM) is the interfacing of all the various manufacturing modules into a unified system, networked to the company's other major systems (finance, distribution etc.). A fully operational CIM system is extremely complex because of its interfaces, and requires a very large investment.
- The computer has also greatly assisted companies in the implementation of flexible manufacturing systems (FMS) and just-in-time (JIT) inventory systems.

Artificial Intelligence (AI). Artificial intelligence concentrates on emulating human reasoning in order to solve problems. AI also thus analyses the methodology of how a human being solves a problem and translates the thought process to the computer. The computer then approaches the human reasoning process to solve the problem in contrast to executing an ordered set of instructions.

Expert systems, neural networks and fuzzy logic are alternative within the artificial intelligence field.

14.11. INFORMATION TECHNOLOGY

14.11.7. General Aspects

Information technology *is defined as the system which collects and processes data and disseminates and spreads information.* It may also be called as a set of organised procedures that when executed, provides information to support the organisation.

Communication, which is a part of information technology, transmits messages through selected channels involving sender and receiver. Information technology is very useful to society as without it no section of society can flourish and prosper.

The basic functions of information technology are depicted in Fig. 14.4.

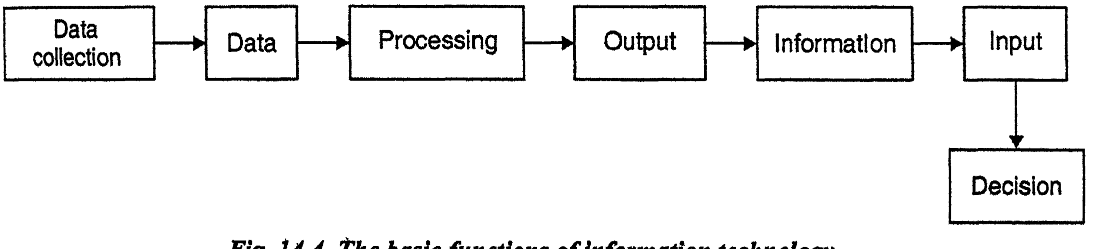


Fig. 14.4. The basic functions of information technology.

14.11.2. Data and Information

Data *is defined as facts which are generally recorded and filed.* It is the raw material which serves as the starting point.

Information *is defined as the processed data which is found handy and useful to arrive at making decisions.* It consists of data that have been retrieved, processed, or otherwise used for informative or inference purposes, argument or as a basis for forcasting and decision analysis.

14.11.3. Information System

The system which collects and processes data and disseminates or spreads information in called **Information system.** It may also be called a set of organised procedures that, when executed, provides informative to support the organisation. The basic functions of an information system are shown in Fig. 14.4.

An information system serves an individual with certain cognitive (faculty of knowing) style faced with a particular decision problem in some organisational setting.

Fig. 14.5 summarises all the variables that *influence the interpretation of an information.*

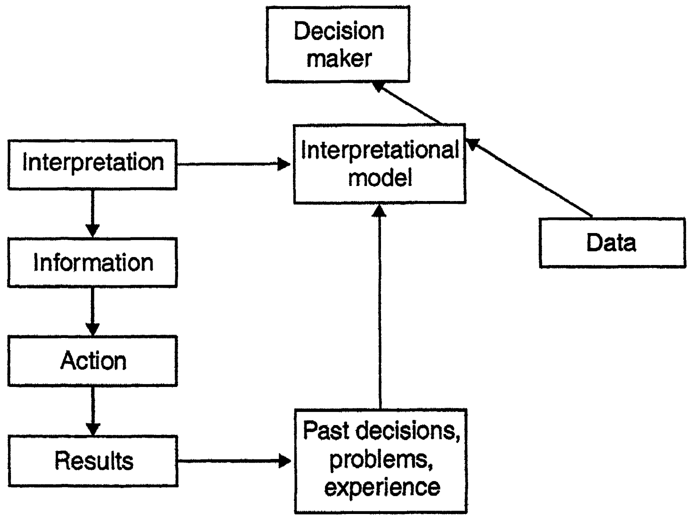


Fig. 14.5. Summary of variables that influence the interpretation of an information.

QUESTIONS WITH ANSWERS

Q. 14.1. Explain briefly the 'Hierarchy of computers in manufacturing'.

Ans. Computers and computer driven devices (*e.g.*, CNC machine tools, robots), in the manufacturing firm tend to form a "*pyramidal control structure*" as shown in Fig. 14.6. The structure represents the common structure that exists between the computers and computer driven devices in the factory.

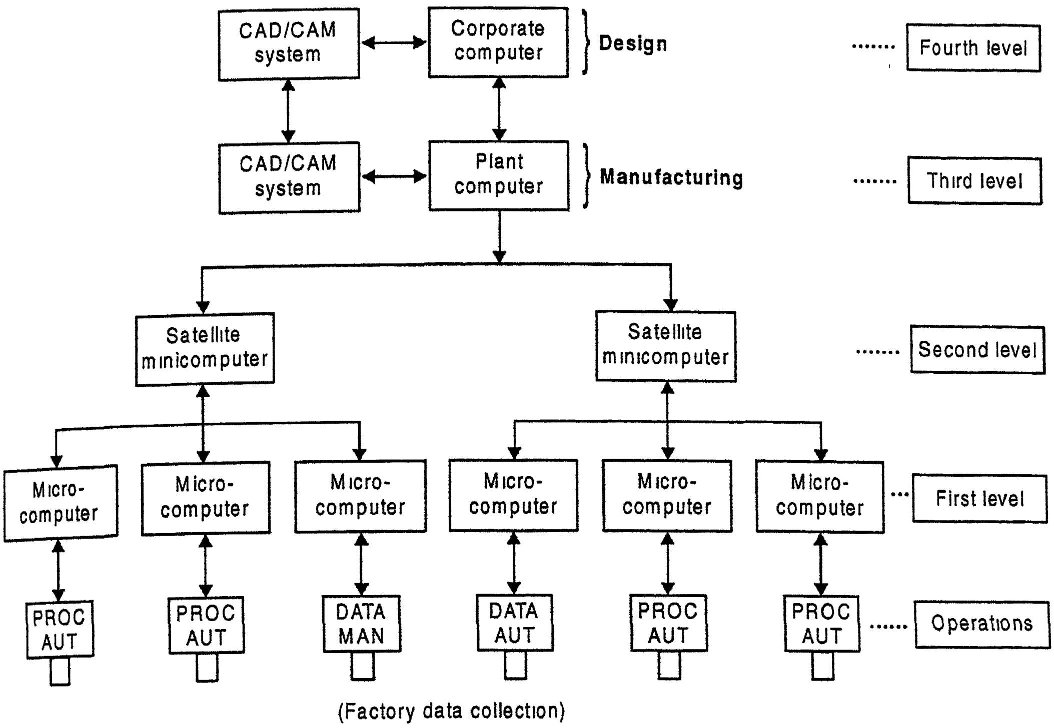


Fig. 14.6. Hierarchy of computers in manufacturing.

The various computers in the hierarchy are fixed together by communication links to a distributed computer system. The individual links provide a computer communications network to forward data and information through the various levels from the manufacturing operations all the way to the corporate computer level. In the opposite direction, product design, process plans production schedules, machine commands and so on are passed down to the individual production cell. *The hierarchy allows for design engineering and manufacturing engineering function to be included within the computer network.*

The following are the *benefits of the hierarchial approach to CIM* (Computer Integrated Manufacture) :

(*i*) In the hierarchial configuration, the software development can be managed more easily since computers are separated with pyramidal arrangement, programming for each project can be handled separately.

(*ii*) The hierarchial computer can be installed gradually rather than all at once.

(*iii*) This structure contains redundancy. In the event of a computer breakdown, other computers in the system are programmed to assume the critical task of the broken-down computer.

Q. 14.2. What is the difference between Computer-Aided-Designed (CAD) and Computer-Aided-Drafting (CAD)?

Ans. Computer-aided-design. It is used for the *initial design of the parts, sub-systems and the total system.*

This process defines all the parameters for construction of the system. Once this design is made, the numerical figures found out of calculations is presented in the form of a rough sketch to the draftsman.

Example : In the design of a beam, the dimensions are to be found out by doing a 'strength analysis'. This does not require any graphical representation. But once design is made, to convey it to the field people for actually building the beam, a *drawing* is required.

Computer-aided drafting :

- It comes into picture *only after the design is completed.* It is *basically used to generate the working drawing to be given to the field or the shop floor to help them in production.*
- Computer-aided-drafting simply provides an *electronic drafting board* to the draftsmen and a lot of electronic tools for creation, modification, storage, retrieval, and outputting of the drawings.

Q. 14.3. What is 'Computer Aided Manufacturing (CAM)'? What are its applications?

Ans. Computer Aided Manufacturing (CAM). *"Computer aided manufacturing is the use of computer to help in the manufacturing or production after the design process.*

- CAM basically produces instructions for the controller, a cutting or processing machine, to automatically perform a set of operations to produce the final product.
- The design outputs of a CAD application, can directly become the input to a CAM system and from the design, directly such a machine control program-called otherwise as *"Numerical Control Code"* can be generated.

— Different machine controllers are available with every type of NC numerical control machine. Each of these controllers support one or more of these languages; ISO, APT, UNIAPT. The output of the CAM system can directly be input into these machines to perform the machining or processing required.

Applications of CAM. Following are the *applications* of CAM.

1. Computer monitoring and control. These are the *direct applications in which the computer is connected directly to the manufacturing process for the purpose of monitoring or controlling the process.*

2. Manufacturing support applications. These are the *indirect applications* in which computer is used in support of the *product operations* in the plant, but there is no direct interface between the computer and the manufacturing process.

- Computer monitoring and control can be separated into monitoring applications and control applications. *"Computer process monitoring" involves a direct computer interface with the manufacturing process and associated equipment and collecting data from process.* The computer is not used to control the operation directly. The *control* of the process remains in the hands of *human operators*, who may be guided by the information compiled by the computer.

Q. 14.4. What is CAD workstation?

Ans. The CAD workstation is the system interface with the outside world. It represents a significant factor in determining how convenient and efficient it is for a design to use the CAD system. The workstation must accomplish the following *five functions :*

1. To interface with the central processing unit.
2. To generate a steady graphic image for the user.
3. To provide digital descriptions of graphic image.
4. To translate computer commands into operating functions.
5. To facilitate communications between the user and the system.

Q. 14.5. List the various input and output devices used for graphics.

Ans. Input devices for graphics :

- Cursor pad or cursors
- Thumb wheels
- Light pens
- Mouse
- Digitizing tablet and table
- Track ball
- Control disc
- Function keys.

Output devices :

The output devices are essentially termed as peripheral associated with the computer. Some of the output devices do not require CRT (Cathode Ray Tube) or interactive display devices. The hard copy output is printed on a paper, magnetic tape, or slide film which can be read and visualised and transported from one place to another without any distortion. Graphics hard-copy devices may be categorised in the three major types namely, *pen plotters*, *electrostatic printers, plotters*, and *computer-output microfilm units*. There are some other types of graphics output equipments such as *photographic devices, like-jet* and *laser plotters*, and *computer-controlled copies*.

Q. 14.6. Discuss briefly the steps in the 'Numerical Control (NC)' in manufacturing.

Ans. Following are the steps which must be accomplished to utilise NC in manufacturing :

1. Process planning.
2. Part programming.
3. Tape preparation.
4. Tape verification.
5. Production.

1. Processing planning :

- The engineering drawing of the workpart must be interpreted in terms of the manufacturing processes to be used. This step is referred to as process planning and it is concerned with the preparation of a route sheet.
- The *route sheet* is a listing of the sequence of operations which must be performed on the work-part.

2. Part programming :

- A part programmer plans the process for the portions of the job to be accomplished by NC.
- There are two ways to program for NC :
  (*i*) Manual part-programming.
  (*ii*) Computer-assisted part programming.

— In *manual part programming,* the machining instructions are prepared on a form called a part *program manuscript.*

— In computer-assisted part programming much of the tedious computational work required in the manual part programming is *transferred to the computer.*

3. Tape preparation :

- A punched tape is prepared from the part programmer's NC process plan.

— In *manual part programming* the punched tape is prepared directly from the part program manuscript or a type writer like device equipped with tape punching capability.

— In *computer assisted part programming,* the computer interprets the list of part programming instructions, performs the necessary calculations to convert this into detailed set of machine tool motion commands, and then controls a tape punch device to prepare the tape for the specific NC machine.

4. Tape verification :

- After the prunched tape has been prepared, a method is usually provided for *checking the accuracy of the tape.*

— Sometimes the tape is checked by running it through a computer program which plots the various tool movements (or table movements) on paper. In this way, major error in the tape can be discovered.

— The "acid test" of the tape involves trying it out on the machine tool to make the part. A foam or plastic material is sometimes used for this layout.

Programming errors are not uncommon, and it may require about three attempts before the tape is correct and ready to use.

5. Production :

- The final step in the NC procedure is to use the NC tape in production. This involves ordering the raw workparts, specifying and preparing the tooling and any special fixturing that may be required, and setting up the NC machine tool for the job.
- The machine tool operator's function during production is to load the raw workpart in the machine and establish the starting position of the cutting tool relative to the workpiece. The *NC system* then takes over and *machines the part according to the instructions on the tape.*

Q. 14.7. Discuss briefly "Applications of Numerical Controls".

Ans. Now-a-days the NC systems are widely used in industry especially in the *metal working* industry. By far the most common applications of NC is for metal cutting machine tools. Within this category, NC equipment has been built to perform virtually the entire range of meterial removal processes including :

— Milling,

— Drilling and related processes,

— Boring,

— Turning,

— Grinding, and

— Sawing.

Following are the *general characteristics of production jobs in metal machining for which numerical control would be most appropriate :*

(*i*) The part geometry is complex.
(*ii*) The parts are processed frequently and in small lot sizes.
(*iii*) Many operations must be performed on the part in its processing.
(*iv*) Much metal needs to be removed.
(*v*) Engineering design changes are likely.
(*vi*) Close tolerances must be held on the workpart.
(*vii*) The parts require 100 percent inspections.
(*viii*) Expensive part where mistakes in processing would be costly.

Q. 14.8. Discuss briefly the steps involved in a computer aided engineering design problem.

Ans. CAD/CAM technology was initiated in the area space industry but is now widely speeding in all industries. It can be defined most simply as *use of computer to translate a product's specific requirements into the final physical products.* With this system a *product is designed, produced and inspected in one automatic process.*

The various steps involved in computer aided engineering design problems are shown in Fig. 14.7.

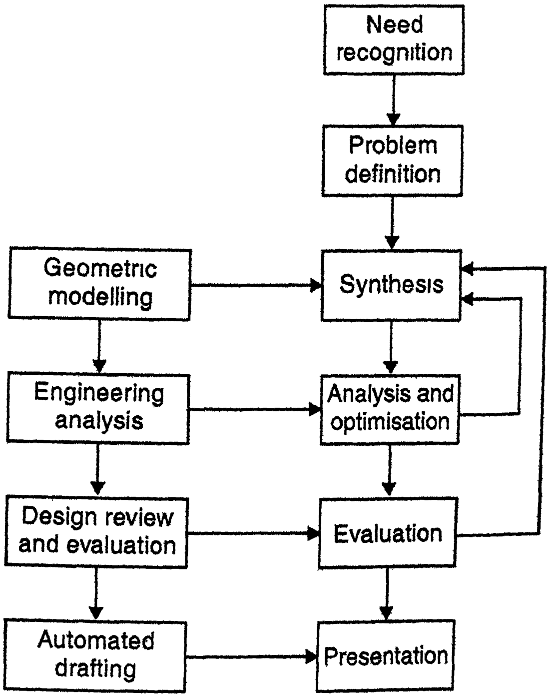


Fig. 14.7. Steps involved in computer aided engineering problems.

HIGHLIGHTS

1. *Computer Integrated Manufacture (CIM)* is the term used to describe the complete and whole automation of the factory with all processes functioning under computer control and only digital information integrating them together.
2. *"Flexible manufacturing"* involves the interconnection of groups of automated machine tools by an integrated and automated material handling system.
3. *Capacity planning* is the method by which the master schedule is adjusted to balance the due dates of jobs or orders against the capacity of the plant and its individual work cells and facilities.
4. *Dispatching* involves the movement of the parts, components, sub-assemblies, and end items so that they arrive at the appropriate work centre exactly at the time they are needed in the production process.
5. A *computer* is a machine that processes data according to set of instructions stored within the machine.
6. A *hybrid computer* is a combination of both analog and digital computers. It is used for simulation applications.
7. A *peripheral* is any device commonly used with a CPU of a computer for input or output of information or for memory functionally separate from the CPU and electronically detachable.
8. The *microprocessor* is a semiconductor device comping of electronic logic circuits manufactured by using either a large scale (LSI) or very-large integratioin (VLSI) technique.
9. A *computer network* is a number of computers interconnected by one or more transmission paths.
10. *Local Area Network (LAN)* provides short range interconnectivity between the devices in the network, normally within one site.
11. A network configuration is called network *topology.*
12. The *transmission line* is the message and data carrying medium that constitutes the physical distribution element of the network.

OBJECTIVE TYPE QUESTIONS

Fill in the Blanks or Say "Yes" or "No" :

1. Numerical control reduces tooling cost by eliminating the costs of sophisticated jigs and fixtures.
2. .... manufacturing involves the interconnection of groups of automated machine tools by an integrated and automated material handling system.
3. Flexible manufacturing systems, (FMSs) are used to complete .... sequences of machining operations on families of manufactured parts.
4. .... eliminate repetitive, manual labour operations.
5. Fixed automation is characterised by extremely low costs associated with equipment procurement.

6. The process .... specifies that sequence of manufacturing operations that is required to produce a product or sub-assembly.
7. The .... planning is the method by which the master schedule is adjusted to balance the due dates of jobs or orders against the capacity of the plant and its individual work cells and facilities.
8. The computer has been the .... of the information age.
9. A .... is an electronic machine for processing information.
10. .... are popularly known as personal computer (P.C.)
11. .... Computer is based on counting operation.
12. A hybrid computer is used for simulation applications.
13. The ALU combined with control unit is called .... processing unit.
14. Chips are rated in terms of their .... and ....
15. Keyboard is the most common and simplest .... device.
16. .... is a pointing device and its size is about the size of palm.
17. Digitizer is similar to light pen.
18. A .... is widely used for playing computer games.
19. .... is also known as core memory, main memory, RAM.
20. .... is a type of memory chip that one can read only and we cannot write on it.
21. ROM is slow.
22. The set of physical components, modules, and peripherals comprising a computer system is called ....
23. The .... is a set of programs required for data processing activities of the computer.
24. All persons concerned with computers, *i.e.*, compiler, programmer, etc. are called. ....
25. Attenuators are used to multiply a variable quantity by a constant.
26. The microprocessor is in many ways similar to the ....
27. A computer network is a number of computers interconnected by one or more transmission paths.
28. LAN provides .... range interconnectivity between the devices in the network, normally within one site.
29. A network configuration is called network ....
30. Coaxial cable is used in vast majority of LANs.

ANSWERS

1. Yes	**2.** Flexible	**3.** sophisticated	**4.** Robots	**5.** No
6. routing	**7.** Capacity	**8.** core	**9.** computer	**10.** Microcomputer
11. Digital	**12.** Yes	**13.** central	**14.** capacity speed	**15.** input
16. mouse	**17.** Yes	**18.** Joy-stick	**19.** Primary	**20.** ROM
21. Yes	**22.** hardware	**23.** software	**24.** liveware	**25.** Yes
26. CPU	**27.** Yes	**28.** short	**29.** topology	**30.** Yes.

THEORETICAL QUESTIONS

1. What do you mean by the term 'Computer Integrated Manufacture (CIM)?
2. Discuss briefly "Integration of design and manufacturing".
3. What do you understand by "Process selection"? Explain
4. What do you mean by "Flexible manufacturing"? Explain
5. Write short note on "Flexible Manufacturing systems (FMSs).
6. Explain briefly the following :
   (*i*) Process routing.
   (*ii*) Capacity planning.
   (*iii*) Intra work cell scheduling methods.
7. Discuss briefly "Basic tools for integration".
8. Briefly discuss "History and development of computers".
9. What is a computer? What are its characteristics?
10. What are the limitations of a computer?
11. How are computers classified?
12. State the differences between 'Analog and Digital' computers.
13. Explain briefly the basic elements of a digital computer with the help of a block diagram.
14. How are the chips rated? Explain.
15. Discuss briefly 'Computer peripherals'.
16. Give the difference between ROM and RAM.
17. Explain briefly the terms : Hardware, Software and Liveware.
18. Discuss briefly the 'computer languages'.
19. Briefly discuss the 'computer programming process for writing programs'.
20. List the computing elements of analog computers.
21. What is a 'microprocessor'? Where are its characteristics?
22. What are the uses of microprocessors in instrumentation?
23. What is computer network?
24. What are the advantages of network?
25. What is 'Local area network (LAN)'?
26. Discuss briefly the more common network topologies.
27. What is Manufacturing Automation Protocol (MAP)? Explain.
28. Explain briefly the following :
    (*i*) Systems software.
    (*ii*) Applications software.
    (*iii*) Artificial Intelligence (AI).
29. Explain briefly the term "Information technology'.
30. What is an 'Information system'? Explain.

15

Group Technology

15.1 General aspects; 15.2. Advantages and limitations of group technology; 15.3. Part families; 15 4 Formation and establishment of component family; 15 5. Collection of production data; 15.6. Classification and codification—Introduction—basic requirements of classification and coding system—advantages of well-designed classification and coding system—classification and coding for group technology. ***Questions with Answers****—Highlights – Objective Type Questions – Theoretical Questions.*

15.1. GENERAL ASPECTS

***GROUP TECHNOLOGY** (GT) *is an approach in which similar parts are identified and grouped together in order to take advantage of their similarities in design and production.* The group technology **aims** at *high productivity at a low cost on short run production.*

- "*Group technology*" in manufacturing, is the replacing of traditional jobbing shop manufacture by analysis and grouping of work into families and the information of groups of machines to manufacture these families on a flow-line principle with the object of minimizing setting times and throughout times.

— The traditional approach of any production unit is to use **"line layout"** where possible and **"functional layout"** in all other cases. In *"line layout"* generally the machines are laid out in a line in their sequence of usage. It is mainly used in simple process industries where all components made on the line use the same machines in the same sequence. In *functional layout* **"batch production"** is used and is based on process specialisation. In this type of factory the workers are divided into organisational units each of which specialises in a particular process or part of a process. This type of layout result in *low machine utilisation and high wastage of time. The high cost of set-ups for small batches results in high manufacturing costs.*

- *Group technology is based on* **"product specialisation"**. *In this case each group of workers specialises in the production of a particular list or family of production and is equipped with all machines and equipment needed to complete these products.*

* Group technology was originated in Russia and was used during World War II.

- Group technology is a new name for production system and many have used different names, *viz.* **"family grouping"**, **"family manufacturing"** etc. to describe this system.

— While examining the meaning of the 'Group technology' one finds that *"Group"* is a number of things classed together, and *"Technology"* is the science of industrial arts. Thus, *"group technology is the science of the industrial arts to a number of things classed together".*

- In *'group technology'* similar parts are arranged into *'part families'*. For example, a plant producing 10000 different part numbers may be able to group the vast majority of these parts into 40 or 50 distinct families. Each family would possess similar design and manufacturing characteristics. Hence the processing of each member of a given family would be similar and this *results is manufacturing efficiencies. These efficiencies are achieved by arranging the production equipment into machine groups, or cells, to facilitate workflow.*

— In product design, there are also advantages obtained by grouping parts into families. *These advantages lie in the classification and coding of parts.*

15.2. ADVANTAGE AND LIMITATIONS OF GROUP TECHNOLOGY (GT)

Following are the *advantage and disadvantages of group technology :*

Advantages. The benefits of group technology are typically realised in the following areas:

(i) ***Product design benefits :***

- In the area of product design, the principle benefit is derived from the use of parts classification and coding system.
- Group technology promotes *design standardisation.*

(ii) ***Tooling and set-ups.*** Group technology tends to promote standardisation of several areas of manufacturing. Two of these are tooling and *set-ups*.

- In tooling, an effort is made to design jigs and fixtures that will accommodate every member of a part's family.
- The machine tools in a GT cell do not require drastic changeovers in set-up because of the similarity in the workparts processed on them. Hence, *set-up time is saved* and it becomes feasible to try to process parts in another so as to achieve a bare minimum of sets changeovers.

(iii) ***Materials handling.*** The group technology machine layout lend themselves to *efficient flow of materials* through the shop. The contrast is sharpest when the flow line cell design is compared to the conventional process-type layout.

(iv) ***Production and inventory control.*** Production scheduling is *simplified* with group technology.

— Grouping of machines into cells reduces the number of production centres that must be scheduled.

— Grouping of parts into families reduces the complexity, and size of the parts scheduling more attention can be devoted to the control of these parts.

Owing to the reduced set-ups and more efficient materials handling within machine cells, *manufacturing lead time and work-in-process are reduced.*

(v) ***Process planning.*** Paper parts classification and coding can lead to an automated process planning system.

— Even without an atomated process planning system, reductions in the time and cost of process planning can still be accomplished. This is done through standardisation. New

part designs are identified by their code as belonging to a certain parts family, for which the general process routing is already known.

(vi) ***Employee satisfaction :***

— The machine cell often allows parts to be processed from raw material to finished state by small group of workers. The workers are able to visualise their contributors to the firm more clearly. This tends to cultivate an improved worker attitude and a higher level of job satisfaction.

— Another employee-related benefit of group technology is that more attention tends to be given to product quality. Workpart quality is more easily traced to a particular machine cell in group technology. Consequently, workers are more responsible for the quality of work they accomplish.

Disadvantages/Limitations :

(*i*) The problem of identifying part families among the many components produced by a plant.

(*ii*) The expense of parts classification and coding.

(*iii*) Rearranging the machines in the plant into the appropriate machine cells.

(*iv*) The general resistance that is commonly encountered when changeover to a new system is contemplated.

15.3. PART FAMILIES

A **part family** or **group** *is a collection of a parts, which either because of geometric shape and size or because of similar processing steps are required in their manufacture.* The parts within a family are different, but their similarities are close enough to merit their identification as members of the part family.

The biggest single obstacle in changing over to group technology from a traditional production shop is the problem of grouping parts into families. There are three general methods for solving this problems.

(*i*) Visual inspection.

(*ii*) Classification and coding by examination of design and production data.

(*iii*) Production flow analysis (PFA).

1. Visual Inspection :

— This method is the *least sophisticated* and *least expensive.*

— It involves the classification of parts into families by looking at either their physical parts or their photographs and arranging them into similar groupings.

2. Classification and coding by examination of design and production data :

— This method *involves classifying the parts into families by examining the individual design and/or manufacturing attributes of each part.* The classification results in a *code number that uniquely identifies the parts attributes.* This classification and coding may be carried out on the entire list of active parts of the firm or some sort of sampling procedure may be used to establish the part families. *Example:* The parts produced in the shop during a certain

given time period could be examined to identify part family categories. The trouble with any sampling procedure is the risk that sample may be unrepresentative of the entire population.

— The method of parts classification and colding *seems to be the most commonly used method today.*

3. Production Flow Analysis (PFA) :

— This method *makes use of information contained on route sheets rather than part drawings.*

— *Worksparts with identical or similar routings are classified into part families.*

- All the above the three methods are *time consuming and involves the analysis of much data by trained personnel.*

15.4. Formation and Establishment of Component family

Formation of component family :

— Initially, a *pilot study* be carried out by examining simple components first, and gradually progressing to the more complex parts. However, the component family analysis should *preferably be based on the complete range of components from the products manufactured by the company.* The drawings and associated production data of the selected components are collected together, classified and sorted into code number order.

— The investigation should not be limited to the formation of potential component families, but also to access the necessary diversity in company operation. This will include the preparation of component family paper work and scheduling and control of the components into the machine group. While this investigation is in progress, the remainder of the drawing, new designs and obsolete drawings still liable to be called forward for spares replacement, should be coded.

— It is *only one-time exercise and effort is fully justified particularly, for variety control and computerization of production planning and control.*

Establishment of component family :

— The coding provides the first stage in sorting and makes it possible to gather the components into families. If tabulated lists are visually examined, the naturally occurring families can be easily determined. These families are normally of the type *'identical in shape and function'* and *'identical in shape but different in function'* and appear as blocks of near identical blocks of code number of listings. These will be the most obvious component families to begin to develop and establish machine groups.

— Finally, recheck the component and tabulations and revise where necessary.

15.5. COLLECTION OF PRODUCTION DATA

- The number and sequence of machining operations, setting times and numbers of each component within a definite period of time used to be collected. By analysis of the *'machining operations and sequence'*, it is possible to *derive the types of machines required to form the machine group.* From the 'machining and setting times' and the numbers of each component, the potential load on the machine group may be established. Line balancing, however,

cannot be adequately established until the component tooling requirements have been assessed. This is the *first stage* in *'family formation'*. The drawing of each component within the family is examined and the type and number of tools necessary to produce the component are determined. With the tooling analysis complete, the family is established and group layout balanced, *i.e.*, data should now include :

(*i*) Geometric shape.
(*ii*) Maximum and minimum size.
(*iii*) Material type.
(*iv*) Form and method of holding.
(*v*) Tools-type and holding.
(*vi*) Machine tools-type and capacity.

From the above information the *profile and parameters of the component family are constructed against which the acceptance or non-acceptance of new components into the family can be used.*

- Once a component family has been formed and integrated into a group layout, it does not necessarily have to remain static. Some components will become obsolete while new components will appear. The more the flexibility that can be built into the system, the more one can expect to get out of it.

15.6. CLASSIFICATION AND CODIFICATION

15.6.1. Introduction

Classification *involves arranging items into groups according to some system whereby like things are brought together by virtue of their similarities and are then separated according to a specific difference.*

A **code** *can be a system used in information processing in which numbers or letters or a combination there of are given a certain meaning.*

15.6.2. Basic Requirements of Classification and Coding Systems

The classification and coding system should meet the following *basic requirements:*

1. To be based upon permanent characteristics.
2. To be mutually exclusive.
3. To be all embracing and offer company wide applications.
4. To be adaptable to computer processing.
5. To be specific to user needs.
6. To be adaptable to future changes.

15.6.3. Advantages of Well-designed Classification and Coding System

The major benefits of a well-designed classification and coding system for group technology have been summarised as followed by Ham :

1. It facilitates the formation of part families and machine cells.
2. It permits quick retrieval of design, drawings, and process plan.
3. It reduces design duplication.

4. It provides reliable workpiece statistics.
5. It facilitates accurate estimation of machine tool requirements and logical machine loading.
6. It permits rationalisation of tooling set-ups, reduces set-up time, and reduces production throughout time.
7. It allows rationalisation of improvement in tool design.
8. It aids production planning and scheduling procedures.
9. It improves cost estimation and facilitates cost accounting procedures.
10. It provides for better machine utilization and better use of tools, fixtures, and manpower.
11. It facilities NC part programming.

15.6.4. Classification and Coding for Group Technology

In group technology, parts are identified and grouped into families for convenience by classification and coding systems, abbreviated as (C/C). This process is a complex and critical first step in group technology. This process is done according to :

- *(i)* ***Design attributes.*** These relate to *similarities in geometric features* of the part.
- *(ii)* ***Manufacturing attributes.*** These relate to *similarities in process involved* in manufacturing of the part.

- Since the above attributes consist of various situations it is time consuming for coding them. So, coding can be done by viewing the shapes of the parts in generic way and then classifying the parts accordingly.
- Parts can also be classified by studying their production flow during the manufacturing cycle; this approach is known as *production flow analysis.*

Coding :

A company can do *coding* on its own method or any of the following methods, depending upon the situation :

- The code structure for part families typically consists of *numbers*, of *letters* or of a *combination of the two*. Each specific component is assigned a code (generally less then 12 digits). This code may belong to design attributes only or to manufacturing attributes only.

Three levels of coding (varying in degree and complexity) are as follows :

(*i*) Monocodes hierarchial coding.
(*ii*) Polycodes.
(*iii*) Decision-tree coding.

(i) **Monocodes hierarchial coding :**

— The interpretation of each succeeding digit depends on the value of the preceding digit.

— Each symbol amplifies the information contained in the preceding digit, so a digit in the code can not be interpreted alone.

- The *advantage* of this system is that *a short code can contain a large amount of information.* But this method is *difficult to apply in a computerised system.*

(ii) **Polycodes :**

— In this code (also known as *chain type*) each digit has its own interpretation, which *does not depend on the preceeding digit.*

— This structure looks to be *lengthy* but it allows the identification of specific parts attributes and it is *suited to computerised system.*

(iii) **Decision-tree coding :**

— This system is also called *"hybrid codes"*.

— It is the *most advanced and it combines both design and manufacturing attributes.*

Coding systems :

Some of the important classification and coding systems include :

- Brisch Systems
- CUTPLA
- Multiclass
- CODE
- D CLASS
- Part Analog System

Here we shall discuss *Optiz* and *Multiclass* systems only.

Optiz system. Prof. H. Optiz (University of Aachen in west Germany) and his co-workers developed this classification and coding system. It represents one of the pioneering efforts in group technology area and is probably the best known of the classification and coding systems.

The Optiz coding system uses the following digit sequence :

12345 6789 ABCD

- The basic code consists of nine digits, which can be extended by adding four more digits. The *first nine digits are intended to convey both design and manufacturing data.* The general interpretation of the nine digits is indicated in Fig. 15.1.

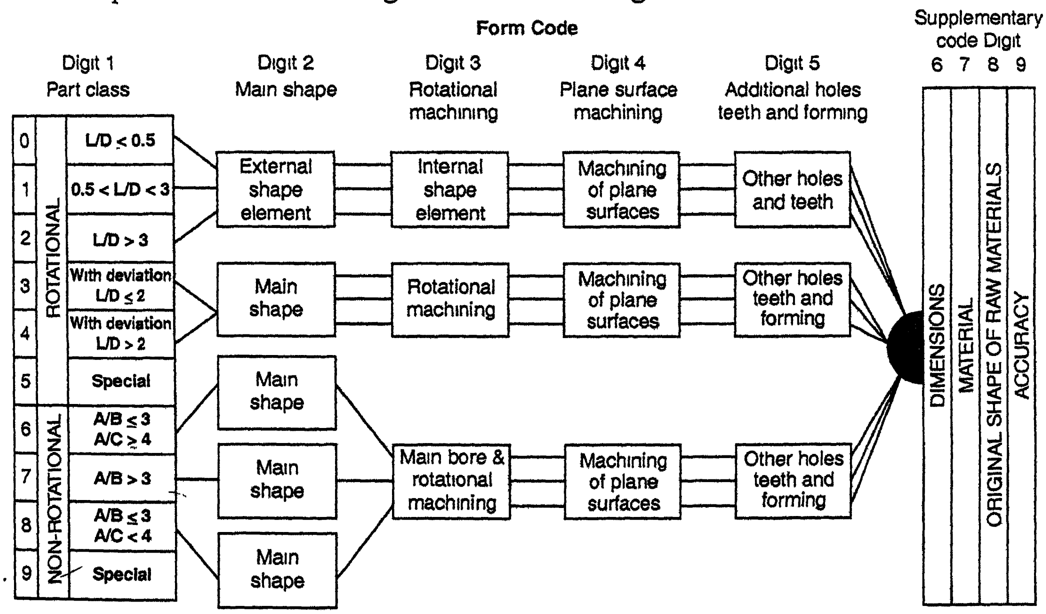


Fig. 15.1. Basic structure of Optiz system.

— The first five digits, 12345, are called **'form code'** and describe the *primary design attributes of the part.*
— The next four digits, 6789, constitute the **'supplementary code'** which indicates some of the attributes that would be of use to manufacturing (dimension, work material, starting raw workpiece shape and accuracy).
— The extra four digits, ABCD, are referred to as the **'secondary code'** and are intended to identify the production type and sequence.

Multiclass system :

This coding system is developed by the Organisation for Industrial Research.

- The system is *relatively flexible*, allowing the user company to customize the classification and coding scheme to a large extent to fit its own products and application.
- It can be used for a variety of different types of manufactured product, including machined and sheet metal parts, tooling, electronics, purchased parts, assemblies and sub-assemblies machine tools and other elements. Upto nine different types of components can be included within a single multiclass software structure.
- This coding systems uses a hierarchial or decision-tree coding structure in which the succeeding digits depend on values of the previous digits.
- In the application of the system, a series of menus, pick lists, tables, and other interactive prompting routines are used to code the part. This *helps to organise and provide discipline to the coding procedure.*
- The coding structure consists of upto 30 digits. These digits are divided into two regions, one provided by OIR and the second designed by the user to identify the type of part.

QUESTIONS WITH ANSWERS

Q. 15.1. What is the basic philosophy of group technology?

Ans. Basic philosophy of group technology is to identify and bring together related or similar parts and processes, to take advantage of the *similarities* which exist between them during all stages of design and manufacture. In this way *part design and process can be standardised and families of like parts can be produced efficiently and economically.*

It may be borne in mind that *there exists relationship between the final or finished products and the components from which they are fabricated.*

Q. 15.2. What advantages can be expected by introducing group technology in an organisation?

Ans. Following are the *advantages of group technology in manufacturing* :

1. Reliable delivery.
2. Reduction of material handling.
3. Use of robots for material handling becomes useful.
4. Space utilisation is more adequately possible.

5. Smaller variety to tools, jigs and fixtures are required.
6. Improved quality of product and less amount of wastage is possible.
7. Improved resource utilisation results in greater amount of output.
8. Finish stock levels are also reduced.
9. Satisfactory work program.
10. Job satisfaction.
11. Standardisation of part design and minimisation of design duplication.

Q. 15.3. Explain the concept of group technology and U-line in the modern production system.

Ans. Group technology :

- Group technology is a concept of grouping machines in *'Group technology cells'* so that parts having similar geometrical and processing features are processed in the same set or group of machines.
- Group technology layout is different from process type layout in which machines are grouped according to their function. Flow of parts through a factory with a group technology layout is *more streamlined* than the flow in a process layout when (quantity to be produced/part variety) or (Q/P) ratio is more.
  - — Very small Q/P ratio suggests the use of process layout and very large Q/P ratio support the use of a flow shop.
  - — *Moderate Q/P ratio demands a group technology layout.*

U-line layout. Refer to Fig. 15.2.

- In flow shop type situations, various arrangements of machines are possible. The common ones are I flow or line flow; L flow when space is a problem, U flow which has feeding to and ejection from the line at the same end.
- A U-line is *easier to supervise.* A U-line can also adopt to different design and give different output rates through the same number of operators. When the flow rate is less, one operator can look after two machines with ease; the machine in front and the machine behind him.

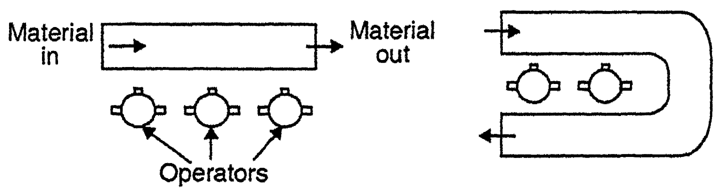


Fig. 15.2.

Q. 15.4. What is group technology? State its area of application.

Ans. Group technology is the realisation that many problems are similar, and that by grouping similar problems, a single solution can be found to a set of problems, thus saving time and efforts.

Group technology is a manufacturing philosophy or principle whose basic concept is to *identify and bring together related or similar parts and processes, to take advantage of similarities which exist, during all stages of design and manufacturing.* It is the replacing of traditional jobbing shop

manufacture by the anlaysis and grouping of work into families and the formation of group of machines to manufacture these families on a flow-line principle with the object of minimising setting lines and throughout times.

- Group technology has become an increasingly popular concept of manufacturing which can be applied in any industry (such as *"machining" "welding", "foundry", "presswork", "forging", "plastic moulding"* etc.) that is designed to take advantage of *mass production layout and techniques, in smaller batch-production systems.*

Features of group technology are shown in Fig. 15.3

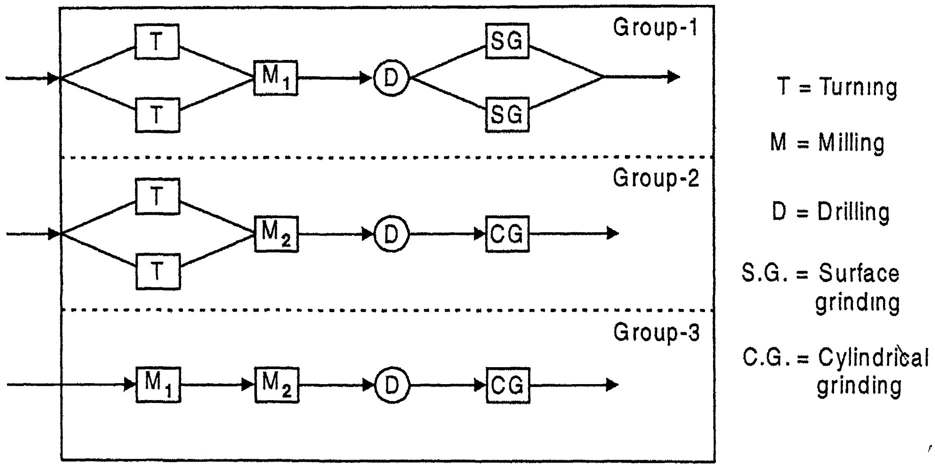


Fig. 15.3. Group layouts.

Q. 15.5. Give the reasons for adopting group technology.

Ans. Modern manufacturing industries are facing a lot of challenges caused by growing international competition and fast changing market demands. These challenges which are examplified in the following list, have and can be successfully met by group technology :

1. There is an industrial trend toward the low-volume production (small lot size) of a wider variety of products in order to meet the rising demand for specifically ordered products in today's affluent societies. In other words the share of the batch-type production in industry is grouping day after day, and it is anticipated that 75 per cent of all manufactured parts will be in small lot sizes.

2. As a result of the first factor, the conventional shop organisation (*i.e.*, departmentalization by process) is becoming very inefficient and obsolete because of the wasteful routing paths of the products between the various machine tool departments.

3. There is no need to integrate the design and manufacturing phases in order to cut short the lead time, thus winning a competitive situation in the international market.

Q. 15.6. What do you understand by 'Production flow analysis'? Explain.

Ans. Production flow analysis (PFA) is a *method for identifying part families and associated grouping of machine tools.* It neither uses a classification and coding system, nor uses part drawings

to identify families. Instead PFA is *used to analyse the operation sequence and machine routing for parts produced in the given shop. It groups parts with identical or similar routings together.* These groups can then be used *to form logical machine cells in a group technology layout.*

Since PFA uses manufacturing data rather the design data to identify part families, it can overcome the following two possible anomalies :

— *First,* parts whose geometries are *quite different* may nevertheless require similar or identical process routings.

— *Second,* parts whose geometries are *similar* may nevertheless require process routings that are quite different.

- However, the *'disadvantage'* of using production flow analysis is that it *provides no mechanism for rationalising the manufacturing routings.* It takes the route sheets the way they, are, with no consideration being given to whether the routings are optimal or consistent or even logical.

The *procedure in production flow analysis* can be organised into the following "steps" :

(*i*) Data collection.
(*ii*) Sorting of process routings.
(*iii*) PFA chart.
(*iv*) Analysis.

Comments on PFA :

— The *weakness* of PFA is that the data used in the analysis are derived from production route sheets. The routings may contain processing steps that are non-optimal, illogical, and unnecessary. Consequently the final machine groupings that result from the analysis may be suboptimal. Notwithstanding this weakness, *PFA has the virtue of requiring less time to perform than a complete parts classification and coding procedure.* It therefore provides a technique that is attractive to many firms for making the changeover to a group technology machine layout.

Q. 15.7. What is 'cluster analysis'? Explain.

Ans. "Cluster analysis" *is employed for the analysis of production flow analysis chart to determine feasible group of processes and their respective packs of parts.* It makes use of algorithms for the study of similarities between objects in a quantitative manner as compared to the classification techniques, which appears to be descriptive.

"Clustering" may be defined as the *science of the classification of objects based on their possession or lack of defined characteristics.* This technique shows an approach to study the similarities between a diverse population of objects in a quantitative manner.

Chustering consists of the following *three stages* :

1. ***Preparing a post-operation matrix.*** This shows whether certain features (like a keyway on shaft) are present or absent.

2. ***Computing a similarity coefficient matrix.*** The buses of this is the extent to which the parts share common characteristics. In this case, coefficient would have a value one (1) when parts are identical and ten (10) when they have no common entity.

3. ***Performing a clustering analysis.*** In this case, the similarity between each pair of objects is examined and group of objects formed such that,within each group, the objects are similar to each other according to set of rules which have been formulated previously.

Q. 15.8. Discuss briefly "cellular and flexible manufacturing".

Ans. For the development of effective quality systems and automation, low volume is a major obstacle. When only a few parts will be produced, little capital is made available for purchasing automated systems and up-to-date test equipment. In addition, other benefits resulting from learning curves and quality feedback may not be possible. Long lead times, high levels of inventory, and poor levels of quality usually result. *Cellular manufacturing* using the techniques of group technology and *flexible manufacturing systems* was developed to help solve these problems. **Cellular manufacturing** *increases the apparent production volumes by grouping similar parts.*

- The **Flexible Manufacturing System** (FMS) is a different approach to development of a specialised production line suitable for many different parts *using sophisticated computer control and a material handling system.*
- — **FMS** *consists of a group of manufacturing workstations connected together by an automated workpart handling system.* The system is capable of simultaneous processing of a variety of different part types at the various workstations under program control.
- — FMS system, however, is a *very expensive bridge for the gap between high-production transfer lines and lower production rates.*

Q. 15.9. Explain briefly "Group technology machine cells".

Ans. The traditional view of GT includes *the concept of "GT Machine cells"—groups of machines arranged to produce similar part families.* This cellular arrangement of production equipment is *designed to achieve an efficient work flow within the cell.* It also results in *labour and machine specialisation* for the particular part families produced by the cell. This presumably raises the productivity of the cell.

Although these advantages exist in GT machine cell, it is a matter of considerable inconvenience and disruption for the shop to make the conversion from a conventional process type layout to the GT cell layout. Today many practitioners argue that it is possible to achieve a good share of the benefits of GT without physically rearranging the machines into cells.

The organisation of machines into cells can follow one of three general patterns :

1. **Single machine cell.** The single machine approach can be used for work parts, whose attributes allow them to be made on *basically one type of process*, such as turning or milling.
2. **Group machine layout :**
   - The group machine layout is a cell design in which several machines are used together, with no provision for conveyorised parts movement between the machines.
   - The cell contains the machines needed to produce a certain family of parts.
3. **Flow line design :**
   - The flow line cell design is a *group of machines connected by a conveyor system.*
   - This design *approaches the efficiency of an automated transfer line.*

HIGHLIGHTS

1. *Group technology* is an approach in which similar parts are identified and grouped together in order to take advantages of their similarities in design and production.
2. Group technology is based on *"product specialisation"*.
3. A *part family* or *group* is a collection of parts, which either because of geometric shape and size or because of similar processing steps are required in their manufacture.
4. *Classification* involves arranging items into groups according to some system whereby like things are brought together by virtue of their similarities and are then separated according to a specific difference.

   A *code* a can be a system used in information processing in which numbers or letters or a combination there of are given a certain meaning.
5. Three *levels* of coding are :
   (*i*) Monocodes hierarchial coding.
   (*ii*) Polycodes.
   (*iii*) decision-tree coding.

OBJECTIVE TYPE QUESTIONS

Fill in the blanks or Say 'Yes' or 'No' :

1. Group technology is based on .... specialisation.
2. Group technology was originated in U.S.A.
3. Group technology is a new name for production system.
4. In group technology similar parts are arranged into .... families.
5. Group technology does not promote design standardisation.
6. Production scheduling is .... with group technology.
7. A .... is a collection of parts, which either because of geometric shape and size or because of similar processing steps are required in their manufacture.
8. Visual inspection method is the least sophisticated and least expensive.
9. Production flow analysis method makes use of information contained on .... sheets than part drawings.
10. A .... can be a system used in information processing in which numbers or letters or a combination there of are given a certain meaning.

ANSWERS

1. product	2. no	3. Yes	4. part	5. No
6. simplified	7. part family	8. Yes	9. route	10. code.

THEORETICAL QUESTIONS

1. What do you mean by 'Group technology'? Explain.
2. List the advantages and limitations of group technology.
3. Discuss briefly "part families".
4. What is 'production flow analysis'?
5. Briefly discuss 'Formation and establishment of component family'.
6. Write short note on 'Collection of production data'.
7. What do you understand by 'Classification and codification'? Explain.
8. What are the basic requirements of classification and coding systems?
9. List the advantages of well-designed classification and coding system.
10. Explain briefly the following three levels of coding :
    (*i*) Monocodes hierarchial coding.
    (*ii*) Polycodes.
    (*iii*) Decision-tree coding.
11. Explain briefly the following coding systems :
    (*i*) Optiz system.
    (*ii*) Multiclass system.

❑❑❑

16

Simulation and Data Base Management System (DBMS)

16.1. **Simulation** – *Introduction—Actıvies involved ın a sımulation process—Types of sımulation methodology—Terms used in simulation; 16.2.* **Data base management system (DBMS)** – *General aspects—Advantages of data base—Basic terminology—Objectives of data base—Aspects regarding data base management—Logical data base structure.* ***Questions with Answers****—Highlights—Objective Type Questions – Theoretical Questıons.*

16.1. SIMULATION

16.1.1. Introduction

Simulation *is the actual running of the model system to gain insight into its performance.*

"Simulation" is used to understand better the expected performance of the real system and to test the effectıveness of the system design. It is thus a descriptive tool, allowing us to experiment with model.

— Simulation experiment requires multiple runs, producing time histories of model variables. Models or model parameters are changed manually or automatically between runs frequently as a result of earlier observations.

- As a result of the growing application of CIM technology, organisations are turning increasıngly to *computer simulation.* **"Computer simulation"** *is technique for examining performance of the model of the real system as it operates over a period of time.* The state of the modelled manufacturing system can be observed while the computer program runs and statistics measuring its performance can be automatically collected.

16.1.2. Activities Involved in a Simulation Process

In a simulation process, the following *three major activities* are involved :

1. **Model development.** Simulation models can be developed by the following four methods :

(*i*) Textile definition.

(*ii*) Graphics definition.

(*iii*) Digitizing.
(*iv*) CAD interfacing.

2. Model execution. Model execution focuses primarily on the execution of the programming statements generated during model development.

3. Model output. Though the development effort and model accuracy remain major concerns of those who must actively perform the simulation, model output has caught the attention of many new simulation enthusiasts.

- In a simulation process, *a model is created to represent a manufacturing system.* The creation of a model requires the following :
- — Definition of the purpose of simulation production output machine utilisation, bottlenecks in production, balancing of resources etc.
- — Specification of the constraints in terms of limits and level of detail-system boundaries resource level.

16.1.3. Types of Simulation

The simulation may be of the following types :

1. Statistical simulation.
2. Continuous simulation.
3. Discrete event simulation.
4. Combined simulation.

1. Statistical simulation :

- This type of simulation is also called *Monte Carlo simulation.*
- It describes systems which can be either stochastic and deterministic static and is used to estimate values that cannot be deduced mathematically.
- 'Statistical simulation techniques' are used widely in *risk analysis for assessing the risks/benefits of different and often expensive decisions.*

2. Continuous simulation :

- The continuous simulation is used to model systems, which vary continually with time. The systems are dynamic but may be either *deterministic or stochastic.*
- It is extensively used where *feedback occurs in a system.*
- The continuous simulation models, often composed of scores of feedback loops and hundreds of differential equations are used extensively in *mechanical, production and electrical engineering.*

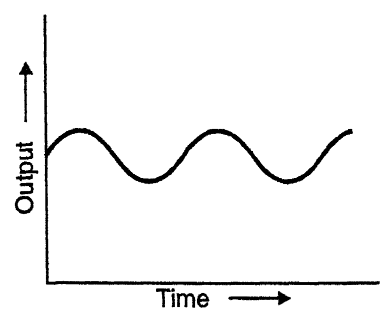


Fig. 16.1. Continuous simulation.

Fig. 16.1 shows a characteristic output from a continuous simulation.

3. Discrete event simulation :

- This type of simulation is concerned with the modelling of systems *that can be represented by a series of events.*
- The simulation describes each discrete event, moving from one to the next as time progresses. The systems modelled *are dynamic and almost invariably stochastic.*
- Descrete models are used in great variety, *e.g.*,

— Air traffic control;
— Ambulance;
— Dispatching;
— Bank operations;
— Job shop scheduling;
— Steel plants;
— Computers etc.

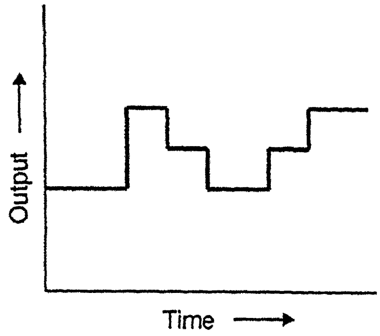


Fig. 16.2. Discrete event simulation.

4. Combined simulation :

- It consists of a *combination of continuous and discrete elements* in the sense that the dependent variables of the models may involve continuous or discrete changes or combination of the true and that the events may be either discrete or continuous in nature.

Example : In a manufacturing system the amount of wear on a tool might be modelled as a continuous variable and the movement of work through the system and the machines discretely.

16.1.4. Simulation Methodology

Simulation can be carried out in the following ways :

1. Developing a dedicated model :

- A system can be modelled by developing a dedicated model using a higher level language (like BASIC, FORTRAN, C) or an object oriented language (C++).
- This method has the advantage of incorporating details specific to a particular system and this can be more efficient.

2. Using simulation software :

- Many general purpose softwares are available in the market, setting upto run the simulation. These include SIMAN, QUEST, SLAM II, MAP/1, SIMPLE 1, CINEMA, SIMFACTORY etc.
- SIMAN a FORTRAN based package, has a lot of capabilities for simulating manufacturing system elements such as stackers, AGVs, and robotic system without writing lot of codes.

Models can be developed on a personal computer, loaded into large computer to get faster running time when required, and the simulation results loaded back into the personal computer for further analysis.

16.1.5. Terms used in Simulation

The various terms used in simulation are briefly discussed as under :

1. Time :

- A discrete-event simulation model is one in which changes in the state of model, called events, are assumed to *take place at discrete points in time.*
- Each point of time at which one or more events take place is called a *"time beat".*

2. Entities and resources :

- The objects, or individuals whose activities are being modelled are represented in a simulation program by *"entities"*, which can be individually identified by their attributes.

— There is an important distinction between permanent and temporary entities. *Permanent entities* are created at the beginning of a simulation run and remain in it throughout, whereas *temporary entities* are created when they are required and disposed of when no longer needed.

- *Resource items* in the simulation are those which do not have characteristics but act as constraints on the activities of the entities.

3. Events :

An event occurs when something happens to an entity at a particular point in time. Following are the two distinct types of events :

(*i*) *Bound event.* It is one whose occurrence is predictable and can thus be scheduled.

(*ii*) *Conditional event.* It is one whose occurence is dependent upon the fulfilment of certain conditions.

4. States and queues :

An entity in a simulation once created, may be in one of three status; *busy, queing,* or *idle.*

- An entity is said to be "*busy*" if it is scheduled to take part in a bound event.
- The entities waiting in turn for some conditions to be satisfied are said to be *"queuing".*

— The most frequently used criterion for selecting entities from a queue is first-in-first-out.

- Entities which are not busy or queing are said of *"idle".*

5. Activities :

- An entity which is busy is said to be engaged in an *activity.*
- An activity diagram describes the life of entities in the system and their interaction with other entities.

6. Executive :

- The executive (or time-advance mechanism) *is the part of the simulation program that ensures that all the events take place in the correct order.*

16.2. DATA BASE MANAGEMENT SYSTEM (DBMS)

16.2.1. General Aspects

- A **data base** *is a complete collection of data, or raw facts, which represents an organisation's information resource.* Since most medium-to-large scale organisations capture and store their data in computer-based systems, *database management activities* are usually associated with *computer processing.* However, effective data base management requires the classical human manager's activities of planning, controlling, organising and communicating.

- The elements of data base management include :
  - — Recognition of data management problems;
  - — Design activity leading to collection, storage and retrieval of data in a manner which effectively support the organisation's need;
  - — Use of computer software called a *data base management system (DBMS)* to facilitate the automated support of data storage and access activity.
- *Data base management activities involve the design, maintenance, and use of collections of data describing an organisation's activities.*
  - — These comprehensive collections of data, called data bases, are usually computerised.
  - — *Software* called a data base management system is used to enhance the effectiveness of data base management by standardising data description and maintenance procedures and by simplifying development of application software which uses the data base.

16.2.2. Advantage of Data Base

The main advantages of data base are :

1. The *use of integrated system is greatly facilitated.*
2. *Information* supplied to managers is more valuable because it based on a comprehensive collection of data instead of files which contain only the data needed for one application.
3. The amount of input preparation needed is *minimised* by the single input principle.
4. A *great deal of programming timing is saved* because the DBMS handles the construction and processing of files and retieval of data.
5. Apart from routine report, it is *possible to obtain ad hoc reports* to meet particular requirements.
6. Errors due to discrepancies between two files are eliminated.

16.2.3. Basic Teminology—The Data Hierarchy

1. Data items :

- *The smallest unit of data that has meaning to its users is called a* **data item.** Traditionally, it is called a *"field"*, a "data element" or *"elementary items"*.
- Data items are *molecules of the data base.* There are atoms and sub-atomic particles composing each molecule (bits and bytes) but they do not convey meaning in their own right and so are of little concern to the users.

Examples (Data items) : Part number of an item, employees number etc.

2. Data Records :

- The data items are *logically grouped together* to form **"Records"** or **"Entities"** and a program usually reads or writes whole records.

Examples : Employee number, name and address; part number, description and denomination of quantity of an item etc.

- A named group of data items within a record is referred to as a *"data aggregate"* or a *"segment"*.

3. Data file :

- A **file** *is a collection of occurrence of a number of record types.*

Examples. A file of employee records, a file of spare parts of a machine etc.

4. Data base :

- *A collection of data designed to be used by different programmers is called a* **data base.**
- The data base is often conceived of a the repository of the information needed for running certain functions in a body such as corporation factory, university or government department. Such a data base permits not only the retrieve of data but also the continuous modification of data needed for the control of operations.

16.2.4. Objectives of Data Base

The main objectives of data base are :

1. *Data independence.*
2. *Data shareability or flexibility.*
3. *Non-redundancy of stored data.*
4. *Relatability :*
   - It is the ability of defining relationship between records of entities at the logical level just as conveniently as defining the records themselves.
5. *Integrity :*
   — The term *"integrity"* refers to a variety of tasks, the main ones being: the coordination of data accessing by different applications; propagation of update of values to other copies and dependent values; and the presenation of a high degree of consistency and correctness of data.

   — A major goal of a data base system is to maintain control over and preserve the integrity of the data base.
6. *Security and privacy :*
   — Data *"security"* refers to protection of data against accidental or international discolsure to unauthorised persons or unauthorised modifications or destruction.

   — *"Privacy"* refers to the rights of individuals and organisations to determine for themselves when, how, and to what extent information about them is to be transmitted to others.

The controls to prevent unauthorised access to data are more intricate and are closely bound up with the data base management software.

7. *Performance and efficiency :*
   — The viability of an integrated data base is highly dependent on good performance and efficiency.
8. *Administration and control :*
   — Overall data base design, data definitions, and the road map users to access the data base must be accomplished by the Data Base Administration (DBA) using specialised data description and control languages, and other facilities.

16.2.5. Aspects Regarding Data Base Management Systems (DBMS)

In a manufacturing organisation, before a DBMS is designed and implemented the following aspects need be considered in detail :

1. Data organisation.
2. Data bases software.
3. Data base management system operations.

1. Data organisation :

Data organisation includes the following :

(*i*) *Schemes and subschemes :*

- These are essentially complete description of all the following as they exist in the data base :

— Area;
— Set occurrences;
— Record occurrences;
— Associated data items;
— Data aggregates.

(*ii*) *Tree and Plex structure:*

- A *tree structure* is a hierarchy of groups of data such that, the highest level in hierarchy has only one group, a *"root"* and all groups except the root, are related to one and only one group on a higher level than themselves.
- A *Plex or network structure* is one in which relationships between records or other groupings can have more than one parent record.

(*iii*) *File addressing:*

— This is the means of assigning data to storage locations and subsequently retrieving them, on the basis of the key of the data.

(*iv*) *Searching :*

— This consists of an examination of a series of items that have desired properties.

(*v*) *Distributed data bases :*

— These are a system of 'data bases' that are in separate geographic locations for various organisational compulsions/conveniences.

2. Data bases software :

The following are the languages and other communication facilities for part of data bases software :

- An on-line data-base interrogation, search and manipulation language.
- The physical data description language.
- Application programming languages.
- The data manipulation language used by the application programmes.
- The scheme (logical data base) description language.
- The subscheme (programmer's data view) description language.
- The data dictionary.
- Inquiry facilities.
- Security control facilities.
- Application program dialogue facilities.

3. Data base management system operations :

— A set of events occurs when a DBMS reads a record from the 'Data base'.

16.2.6. Logical Data Base Structures

Most data base management softwares manipulate a data base by using one of the following three data structures :

1. The hierarchial or tree model.
2. The network or plex model.
3. The Relational model.

1. The hierarchial or tree model :

— In this model, data files are arranged in a tree like structure, which facilitates searches along branch lines, records are subordinated to other records at a highest level. Starting at the node of the tree, each file has one-to-many relationship to its branches.

Example : A *parts list,* in which each product is composed of subassemblies and/or component parts.

2. The network or Plex model :

— It is combination of several hierarchies in which child files have more than one parent file, thereby establishing a many-to-many relationship among data. A hierarchical model is actually a subject of a network model.

— TOTAL and IDMS languages are examples of network data base languages.

- In both hierarchical and network data bases, data relationships are predefined and embedded in the structure of data base. *Access to data is processed by associated application programmes.*
- Both the hierarchical and network data bases are *suited for batch operations that are highly structured and repetitive involving high transaction rates.*

3. The Relational model :

— In a Relational Data Base Management System (RDBMS) an entity is an object that is distinguishable from other objects.

— An entity set is a set of entities of the same type and is represented by a set of attributes. For each attribute there is a set of permitted values for domains. An entity relationship model is based on the perception of the real world which consists of set of entities and relationship among them.

— The RDBMS *eliminates the need to follow predefined access paths to reach target data and makes data access more flexible. The access is independent of the way it is stored.*

— Several vendors now offer RDBMS suitable for CIM application.

QUESTIONS WITH ANSWERS

Q. 16.1. Discuss briefly "computer simulations".

Ans. Computer simulations involve a time dimensions (dynamic behaviour), and they fall into *three broad categories :*

1. Simulation of business or industrial engineering systems which includes such problems as :

— Control of inventory levels;

— Job-shop scheduling;

— Assembly-line balancing.

2. Simulation of an engineering system or process by mathematical modelling and computer simulation.

Example. Simulation of a traffic control problem or the solidification of a large steel casting.

3. Simulation gaming (not to be confused with game theory) in which live decision makers use a computer model for complex situations involving military or management decisions.

Example. A game for bidding strategy in the construction industry.

Q. 16.2. What is simulation? Explain.

Ans. Simulation *is the process of building, testing and operating models of real-world phenomenon through the use of mathematical relationships that exist among critical factors.* Their technique is *useful for solving complex problems that can not be readily solved by other techniques.*

The simulation involves the following *"steps"* :

1. To generate random numbers.
2. To generate random samples for all the random variables associated with the system.
3. To simulate the model to the desired number of times.
4. To draw conclusion or optimise the systems.

- *"Simulation techniques"* are especially applicable to what-if-problems, in which a manager or technician wants to know, if we do this, what will happen. *Simulation can be conducted by the manipulation of physical models.*

Example. One might have a physical model of a machine and actually keep on increasing its speed to determine at what point it would begin to jam, fly apart or walk across the floor. With no loss, one may, instead, use a mathematical model in which each of the item represents one of the variables, and serves the effect on the others when different values are given to one or more of the terms. With the help of computers, it is possible to examine what will happen in an enormous number of cases—without spending a prohibitive amount of time.

— Because large electronic computers have become easily accessible in recent years, management can simulate complex situations in order to determine the best course of action.

- A *simulation model can be deterministic* if the manager knows exactly the value of the factors he employs in the equations. However, *simulation is essentially probabilistic,* since the manger typically must estimate the future values of these factors. Thus, *with the help of simulation, the management decision making becomes very easy.*

Q. 16.3. What are the uses of 'Simulation tools'?

Ans. As simulation tools become more popular and their benefits become more recognised, the uses and application of these tools will continue to grow. Following are some important applications of 'simulation tools' :

1. Material handling systems.
2. Material handling with overhead cranes.
3. Paper flow in an office environment.
4. Computer network design.
5. Flexible Manufacturing System (FMS) design.
6. Retail and consumer outlet design.
7. Warehouse and distribution system design.
8. Continuous improvement strategies.
9. Operations training.

Q. 16.4. Explain briefly why simulation tools should be used ?

Ans. Simulation packages are very powerful tools. They add significant insight and understanding about the planned or existing facilities under investigation. *Simulation tools have a very solid place in the overall design and evaluation process.* Simulation must, however, be used at the appropriate time during the project life cycle. *Simulation does not replace the fundamental engineering that must take place before simulation is used.*

Following are the *reasons* why simulation tools should be used :

1. ***Concept of randomness :***

- In complex systems, where many sources of variability and randomness usually exist, simulation tools are valuable in analysing the complex interactions of the numerous random variables.
- Simulation is used by the analyst to *evaluate and determine what expected outcome or results are most likely to be.*

2. ***Payback :***

- Frequently the payback is *ten* times greater than the cost of simulation study, with a breakeven point of less than one year.
- Savings are in the form of :

— capital expenditure reduction or avoidance;
— operating cost reduction;
— reduction in required inventory levels;
— increase in through put;
— decrease in the number of people required.

3. ***Insurance :***

- The use of simulation tools provides the comfort and security of knowing the facility the design will provide to the anticipated results.
- Simulation ensures that an effective solution is planned. Of course, a proper implementation of the plan is still required for success.

4. ***Communication improvement :***

- Animation is essentially important when the results are not intuitively obvious.
- In addition to the animation, a thorough simulation modelling methodology ensures that information and assumptions are understood by all pertinent people and departments.

5. ***Goal setting for vendors supplying equipment :***

- The evaluation of the vendor's equipment and its interaction with other systems focuses on determining whether the facility meets *its goals and objectives.*
- The simulation model is used to evaluate the speed or throughput rate of the equipment, the setup time, the repair time, the frequency of unplanned down time and the scheduling rules for loading the equipment.

6. ***Continuous improvement :***

- The continuous improvement philosophy and process is a *rapidly growing strategy.* Simulation is a very valuable tool for focussing a company's resources during this improvement process.

- Although the philosophy's goal is to empower the entire organisation in this process, there is a need to prioritize and focus the efforts in the areas yielding the largest gains.

7. ***Evaluation of operating philosophies :***

- Simulation provides an experimental test environment for evaluating different operating philosophies.
- Before committing your organisation to the current trend in the industry, use an appropriately developed simulation model of your facility to compare the new way of doing business against the current method and determine what the expected impact should be.

8. ***Test environment :***

- The usefulness of simulations on a test environment can not be over stated.
- If the area under evaluation does not exist, simulation provides a very valuable way to test the ideas and plans. This is accomplished before any capital investment is made.

Q. 16.5. What are the major parameters which should be considered in obtaining a commercial DBMS?

Ans. The following major parameters should be considered in obtaining a commercial DBMS :

1. Data base definition.
2. Screen display design.
3. Report design.
4. Processing design.
5. Data editing or validation.
6. Access to records.
7. Data base capacity.
8. Performance.
9. Security and privacy.
10. Data backup and recovery.
11. Availability of fourth-fifth-generation retrieval languages.
12. Integration capabilities.
13. Business graphics.
14. Spread sheets.
15. Communications.

Q. 16.6. Discuss the reasons behind need of database for a manufacturing company.

Ans. By Data base *we mean an integrated collection of data that allows access to information required of interest to an organisation.*

A computer integrated manufacturing system requires a single data base which is shared by the entire manufacturing organisation. Data bases consist of up-to-date information on designs, machines, processes; materials, production, finances, purchasing, sales, marketing and inventory etc. This vast data is stored in computer memory and recalled or modified when ever needed by department individuals in organisation or by CIM system itself.

Data bases, as mentioned above, consist of up-to-date, detailed and accurate data relating to various department of an organisation, therefore, their need arise for all departments concerned with

manufacturing and other related activities. In any modern organisation *data base is a must to control, speed up activities and to watch production and sales activies.* Data base is also of use *for decision making at a higher level.*

Q. 16.7. Explain the role of data base management system in a flexible manufacturing system.

Ans. The elements of data base management include recognition of data management problems, design activity leading to collection, storage retrieval of data in a manner which effectively support the organisation's needs and use of computer software called a *data base management system* (DBMS).

It facilitates the automated support of data storage and access activity. The important tasks takes up by DBMS is to provide automated, manufacturing system required support by providing data base with the help of computers. Flexible manufacturing system (FMS) is a specialised production line suitable for many different parts using sophisticated computer control and a material handling system. FMS consists of a group of manufacturing workstations connected through by air automated work part handling system. A FMS *represents a total approach to machining parts in random order, workpieces move from machine to machine in random sequence on an integral handling system.*

In FMS parts are selected to be manufactured because they require the same machining operations, parts need not be similar. The machine tools in the system are determined by the expected variety of parts to be machined. The entire FMS is *controlled by a supervisory computer which manages the processing of all parts in the system.* The computer controls and optimises best use of all machine tools within the system because it knows which ones are work in and when they will be idle. This computer also provides management information.

By understanding clearly what FMS is, we can easily realise the use of data base management system.

HIGHLIGHTS

1. *Simulation* is the actual running of the model system to gain insight into its performance.
2. 'Computer simulation' is a technique for examining performance of the model of a real system as it operates over a period of time.
3. In a *simulation process,* a model is created to represent a manufacturing system.
4. The simulation may be of the following types :
   (*i*) Statical simulation.
   (*ii*) Continuous simulation.
   (*iii*) Discrete event simulation.
   (*iv*) Combined simulation.
5. A *data base* is a complete collection of data, or raw facts, which represents an organisation's information resource.
6. Data base management activities involve the design, maintenance, and use of collections of data describing an organisation's activities.
7. Relational data base management system (RDBMS) eliminates the need to follow predefined access paths to reach target data, and makes data access more flexible.

OBJECTIVE TYPE QUESTIONS

Fill in the Blanks or Say 'Yes' or 'No' :

1. .... is a descriptive tool, allowing us to experiment with model.
2. .... experiment requires multiple runs, producing time histories of model variables.
3. .... simulation is a technique for examining performance of the model of a real system it operates over a period of time.
4. .... execution focusses primarily on the execution of the programming statements generated dressing model development.
5. In a simulation process, a .... is created to represent a manufacturing system.
6. Statistical simulation is also called .... simulation.
7. .... simulation is extensively used where feedback occurs in a system.
8. Discrete event simulation in concerned with the modelling of systems that can be represented by a series of events.
9. Each point of time at which one or more events take place is called a ....
10. An .... occurs when something happens to an entity at a particular point in time.
11. A .... event is one whose occurence is dependent upon the fulfilment of certain conditions.
12. A bound event is one whose occurrence is predictable and can thus be scheduled.
13. An entity is said to be .... if it is scheduled to take part in a bound event.
14. Entities which are not busy or queing are said to be ....
15. The .... is the part of the simulation program that ensures that all the events take place in the correct order.
16. The smallest unit of data that has meaning to its users is called a ....
17. Data items are .... of the data base.
18. A collection of data designed to be used by different programmes is called a ....
19. .... is the ability of defining relationship between records of entities at the logical level just as conveniently as defining the records themselves.
20. File .... is the means of assigning data to storage locations and subsequently retrieving them, on the basis of the key of the data.

ANSWERS

1. Simulation	2. simulation	3. computer	4. Model	5. model
6. Monte Carlo	7. continous	8. Yes	9. time beat	10. event
11. conditional	12. Yes	13. busy	14. idle	15. execition
16. data item	17. molecules	18. data base	19. Relatability	20. addressing.

THEORETICAL QUESTIONS

1. What do you understand by the term 'simulation'? Explain.
2. Discuss briefly the activities involved in a 'simulation process'.
3. Enumerate and discuss briefly various types of simulations.
4. Explain briefly any two types of the simulation :
  (*i*) Statistical simulation.
  (*ii*) Continuous simulation.
  (*iii*) Discrete event simulation.
  (*iv*) Combined simulation.
5. Discuss briefly 'simulation methodology'.
6. Explain briefly the following terms used in simulation:
  (*i*) Time.
  (*ii*) Entities and resources.
  (*iii*) Events.
  (*iv*) States and queues.
  (*v*) Activities.
  (*vi*) Executive.
7. Explain briefly the following terms :
  (*i*) Data base.
  (*ii*) Data base management activities.
  (*iii*) Data base management system (DBMS).
8. List the advantages of data base.
9. Discuss briefly the following terms :
  (*i*) Data items.
  (*ii*) Data records.
  (*iii*) Data file.
10. What are the main objectives of data base? Explain.
11. Discuss briefly the following :
  (*i*) Data organisation.
  (*ii*) Data bases software.
  (*iii*) Data base management system operations.
12. Explain briefly the following :
  (*i*) The hierarchical or tree model.
  (*ii*) The network or Plex model.
  (*iii*) The Relational model.

❑❑❑

17

Elements of Integration

17.1. COMPUTER INTEGRATION MANUFACTURING

The *computer integrated manufacturing (CIM)* is the best context in which *industrial controls and sensors* can be understood. This concept, in some quarters, was formerly called *hierarchical control.* This concept is *applicable in both* ***"manufacturing"*** *and the* ***"process"*** *industries.* The structure is very similar, although different terms are used at certain levels, as discussed below.

Sensors and actuators. These devices provide the interface between the *controller and machine or process being controlled.* ***"Sensors"*** *translate some variables on the machine or process to a signal* (usually electrical) *that can be subsequently processed by the control equipment to obtain the current value of the variable of interest.*

Sensors can be either continuous or discrete.

Examples. '*Continuous*'—Measurement devices for temperatures, pressures, flows etc.
'*Discrete*'—Proximity switches, limit switches, on/off level switches etc.

"Actuators" *accept a signal from the control system and in some fashion impose this signal on the machine or process being controlled.*

Examples: '*Continuous*'—Variable speed drives, pneumatic positioning valves etc.
'*Discrete*'—On/Off motors, solenoid valves etc.

Machine or regulatory control. Functions at this level provide the basic regulation of the machine or process being controlled.

- For a ***machine***, regulatory control is provided by *controllers* such as *numerical controllers or programmable logic controllers.*

- For *processes*, regulatory control is provided by *single-loop* or *multi-loop microprocessor—based controllers.*

Cell control or supervisory control :

- In *"manufacturing facilities"* several machines are often grouped to form a *cell.*
- In *"process plants"*, several unit operations are *interconnected* to form the process.

Plant control. At this level reside the various functions required for efficient operation of the entire plant. *Functions* at this level include :

— Keeping track of the raw materials and products;
— Routing production activities throughout the plant;
— Monitoring equipment utilisation etc.

- The computers at this level communicate with the cell or supervisory computer in a plant local area network (LAN).

Corporate :

- Normally implemented as part of the management information system (MIS) capabilities, functions at this level are directed to the long term or strategic issues.
- An essential part of this function is the collection, analysis and presentation of information to corporate-level managerial personnel.

17.2. MECHANISATION AND AUTOMATION

The **mechanisation** (*the precursor to automation*) *can be defined in its simplest sense as the transfer of skills and manual activities to machine operations.*

The primary difference between mechanisation and automation includes *feedback for controlling an automated system.*

"Microautomation" differs from "macroautomation" in that the latter pertains to *the low-level control system commonly envisioned for industrial automation.*

1. "Microautomation" is primarily concerned with logical control focused on *individual machines* and the logical linkage between machines and devices. In particular microautomation pertains to *servomechanism, hydraulic and pneumatic devices* and associated low-level software used for physical movement of parts through a production system which typically results in "islands" of automation.

2. "Macroautomation" as the term indicates, has a larger scope and *deals with the coordination and supervision of various smaller scooped islands of automation.* This has led to various models and landings for communications and control of large-scale manufacturing (automated) system. Pertinent issues include refractive models and corresponding architectures for implementation of large scale systems.

17.3. AUTOMATION AND PRODUCTION

While classifying automated production systems, production volume and product variety need be considered. As noted by Grover, such systems can be *classified* into three basic types :

1. Fixed automation :

- The fixed automation is characterised by having the sequence of operations necessary to manufacture or assemble a product fixed by the equipment configuration. As such, there is typically equipment which is inflexible to product changes.
- Its advantage is *high production rates.*

2. Programmable automation :

- Programmable automation equipment is highly reprogrammable to accommodate high product variety but has low production rates relative to fixed automation.
- Parts are typically loaded into programmable automated production system in batches. Each batch consists of a different part; and the machines comprising the systems to manufacture the part are reprogrammed for each batch. Change-over from one batch to the next also requires a change in physical set-up of the machines tools, that is their fixing and tooling. Such change-over results in a loss of production time.

  Example. Numerically controlled (NC) machine tools and industrial robots.

3. Flexible automation :

- Conceptually, a flexible automated system has the *capability of producing a variety of parts with minimal changeover time from one part to the next.* The ability to change part programs and to change the physical set-up of the production system with little or no loss of production time is the primary difference between flexible automation and programmable automation.
- To accomplish this, one strategy has been to formulate flexible manufacturing class based on group technology principles. The overall objective is to increase productivity by properly designing a flexible system that offers advantages similar to fixed automation schemes of mass production but has capability for handling part variety.

17.4. MECHATRONICS AND CONCURRENT ENGINEERING

The *concept of "Mechatronics"* (originated by Japanese in the early 1970s) *is clearly related to the issues of robotics and flexible automation.*

Mechatronics has been described as *"the union of mechanical and electronic engineering needed in producing the next generation of machines, robots and smart mechanisms for applications such as manufacturing, large-scale construction and work in hazardous environment."* It is a multi-disciplinary approach using integrated terms of designers, manufacturing engineers, purchasing, marketing, and sales personnnel to design both the product and the system to manufacture it.

Complementary to the term mechatronics would be **concurrent** (*simultaneous*) **engineering,** which is a term more prominent in U.S. industries.

The focus is being given on four key areas in regard to concurrent engineering. These areas are, in many ways, fundamental to the existing discipline of industrial engineering and its future development include:

— Intelligent computer-aided design;
— Intelligent manufacturing systems;
— Human-machine interface;
— Maintenance.

The *function of "mechatronics"* or in more general terms, *"concurrent engineering",* is *to provide a national framework for the integration and implementation of the various sub-systems which comprise the disciplines and organisational functions of an engineering and manufacturing facility.*

17.5. INDUSTRIAL ROBOTS

17.5.1. Introduction

According to the Robotics Industries Association (RIA) an industrial robot is *defined* as under :

"*An* **industrial robot** *is a reprogrammable, multi-functional manipulator designed to move materials, part tools, or special devices through variable programmed motions for the performance of a variety of tasks.*"

This definition is compatible with the classification of programmable automation, but robots are also used in flexible automation and fixed automation systems. *Example.* An automation line using many robots to perform spot welds in which robot programs are downloaded from a computer to a specific robot controller could be considered a high-production flexible automation system.

17.5.2. Objectives of Using Industrial Robots

The use of *Industrial Robots* is increasing day-by-day with a view to achieve the following *main objectives* :

1. To reduce production time.
2. To minimise the labour requirement.
3. To raise the quality level of products.
4. To increase productivity.
5. To improve existing manufacturing processes.
6. To enhance the life of production machines.
7. To minimise the loss of man-hours on account of accidents and diseases.
8. To make the reliability and applicability of new high-speed production processes and their related machinery possible.
9. To take advantage of fatigue-free continuous deployment of robots, because the human beings are always bound to experience fatigue when put to continuous working.

17.5.3. Advantages of Employing Robots

Followings are the *advantages of employing robots* :

1. Lifting and moving heavy objects.
2. Working in hostile environments.
3. Providing repeatability and consistency.
4. Working during unfavourable hours.
5. Performing dull or monotonous jobs.

17.5.4 Robot Components

The *main components of a robot* are as follows:

1. **Base :**
   - The base may be fixed on mobile.
2. **Manipulator arm :**
   - This arm is provided with a number of degrees of freedom of movement.
3. **Gripper or end effector :**
   - It is used for holding a piece or a tool, depending upon the application of the robots.

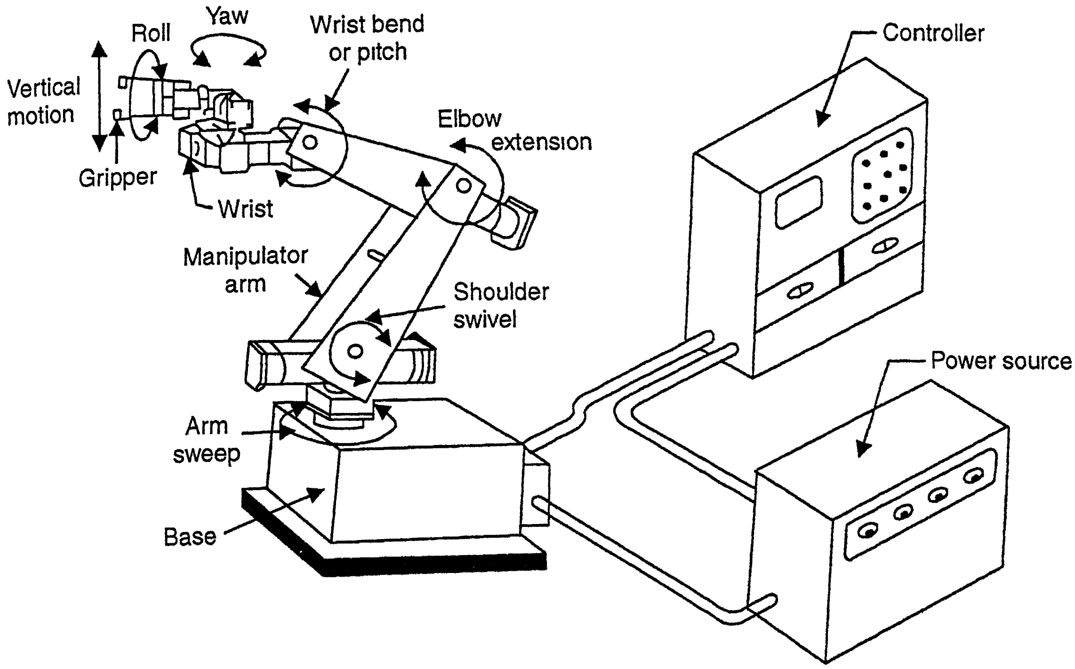


Fig. 17.1. Main components of a Robot and the basic motions.

4. Drives :
- The drives are also known as "*actuators.*"
- They move the manipulator arm and end deflector to the required position in space.

5. Controller :
- It delivers commands to the actuators with the help of hardware and software support.

6. Sensors :
- They perform the following *functions*:
  (*i*) To act as feedback devices to direct further actions of the manipulator arm and the end effector (gripper), and
  (*ii*) To interact with the robot's working environment.

Power source :

The power source is the source of energy used to move and *regulate the robot's drive mechanisms*. The energy comes from three sources : *Electric, hydraulic* and *pneumatic.*

- ***Electric drives*** are *clean and quite* with a *high degree* of *accuracy* and *repeatability.* They also offer a *wide range of payload capacity*, accompanied by an equally wide *range of costs*
- ***Hydraulic drives*** today's most popular, have *high payload capacities* and are relatively easy to maintain. They are, however, rather *expensive* and *not as accurate as either the electric or pneumatic drives.*
- ***Pneumatic drives*** although limited to *smaller payloads*, are *relatively inexpensive, fast and reliable.*

Basic Motions :

The *six basic motions* or degrees of freedom are as follows (See Fig. 17.1).

1. Vertical motion. The entire manipulator arm can be moved up and down vertically either by means of the *shoulder swivel, i.e.*, turning it about a horizontal axis,, or by sliding it in a vertical slide.

2. Radial motion. Radial movement, *i.e., in* and *out* movements, to the manipulator arm is provided by *Elbow extension* by extending it and drawing back.

3. Rotational motion. Clockwise or anticlockwise rotation about the vertical axis to the manipulator arm is provided through *Arm sweep.*

4. Pitch motion. It enables up and down movement of the wrist and involves rotational movement as well. It is also known as *wrist bend.*

5. Roll motion. Also known as *wrist swivel,* it enables rotation of wrist.

6. Yaw. Also called *wrist yaw,* it facilitates rightward or leftward swivelling movement of the wrist.

17.5.5. Robot Classification

Two *standard classifications* suggested by Engelberger are:

1. Mechanical configuration based.
2. Control method based.

— The classification based on '*mechanical*' *representation* considers the *various joints and links* comprising the physical structure of the robot and their relationship to each other.

— The classification by '*control*' pertains to the type of *technique implemented to control the robot.* This classification considers the following subclasses: *Non-servo controlled* and *servo-controlled.*

Each of these classification techniques is discussed as under :

1. Mechanical configuration. The majority of commercially available industrial robots can be grouped into *four basic configurations:*

(*i*) Polar configuration.
(*ii*) Cylindrical configuration.
(*iii*) Cartesian coordinate configuration.
(*iv*) Jointed-arm configuration.

(*i*) ***Polar configuration.*** Refer to Fig. 17.2.

— This configuration has a telescopic arm which pivots about a horizontal axis and also rotates about a vertical axis.

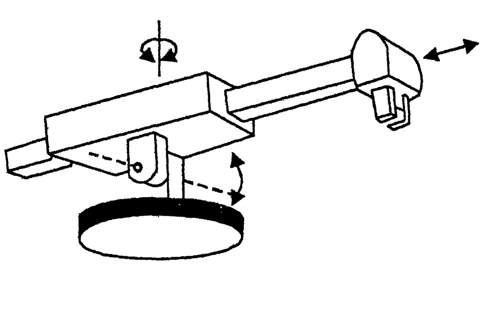


Fig. 17.2. Polar configuration.

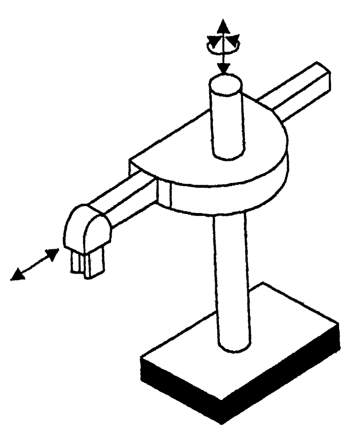


Fig. 17.3. Cylindrical configuration.

— The work volume, a term referring to the space within which the robot can manipulate the wrist end, thus defines a spherical volume in which the robot can perform its task.

(*ii*) ***Cylindrical configuration.*** Refer to Fig. 17.3.

— Cylindrical configured robots use a vertical column with the robot arm attached to a side which can move up and down the column.

— Simultaneously, the arm can move radially with respect to the column.

(*iii*) ***Cartesian coordinate configuration.*** Refer to Fig. 17.4.

— The cartesian or rectilinear robot also termed as *gentry robot*, has three mutually perpendicular axes which define a rectangular work volume.

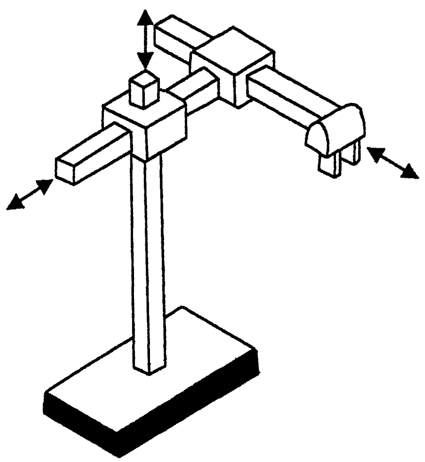


Fig. 17.4. Cartesian configuration.

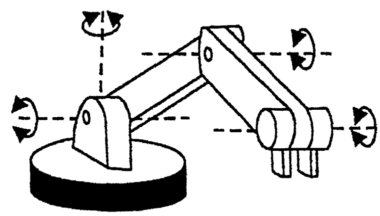


Fig. 17.5. Jointed-arm configuration.

(*iv*) ***Jointed-arm configuration.*** Refer to Fig. 17.5.

— The jointed-arm robot most resembles an human arm and consists of a series of links connected by rotary joints which when referenced from the base are referred to as the shoulder, arm and wrist joints.

— Regardless of configuration, the function of the robot arm configuration is to position a wrist assembly which orients an end effector to the proper position and orientation (jointly referred to as the POSE) dictated by the task at hand.

Fig. 17.6 shows the degree of freedom associated with a robot wrist

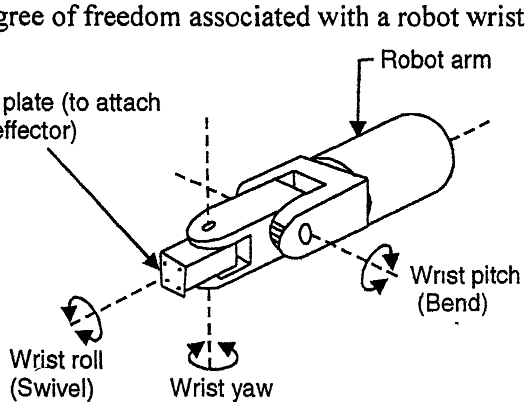


Fig. 17.6. Degrees of freedom associated with a robot wrist.

2. Control classification. Several techniques have been developed to control the various axes of a robot simultaneously.

- The simplest type of control is the ***"non-servo controlled"*** or *"limited-sequence robot"*.
  - — Non-servo-controlled robots are also called *limited-sequence robots, end-point robots, pick and place robots* or *bang-bang robots*. Such a robot is controlled by setting mechanical stops or limit switches to establish end points of travel of each joint. The mechanical set-up to give the proper position and sequence of stops serves as a rudimentary programming approach rather than a computer-intensive robot programming language.
- For more complex control and greater flexibility, current industrial practice employs *servo-controlled robots.*
  - — The servo control of an industrial robot is accomplished by comparing feedback information to the command input such that a desired trajectory will be followed, that is, a *closed-loop system.* Feedback information on position, velocity, or other physical variables is provided by continuously monitoring the variables of interest. Several sophisticated foot arm control techniques and algorithms have been developed for robot controllers.
  - — Servo-controlled robots can be *classified* as playback robots with *point-to-point* (PTP) control or playback robots with *continuous path* (CP) control.

Mechanical inaccuracies result from the various errors that can occur in a robots's construction or operation. These include *gear backlash, stretching of pulley cords, leakage of fluids* or *material and structural imperfections.* Such errors degrade the overall accuracy of the robot and are magnified when the arm is fully extended. Mechanical inaccuracies are principally responsible for repeatability errors. A robot manufacturer typically specifies repeatability as the radius of an idealised sphere and expresses the specification as a plus or minus value. The majority of robots have extremely high repeatability (can be ± 0.001 inch or less) but many of these robots can have comparatively greater inaccuracy values.

17.5.6. Control System and Components

A brief overview of the control structure actuation devices, grippers and types of sensors that may be used with an industrial robot is given below :

1. Controller :

- Its function is to control the manipulator as programmed by the user to perform the prescribed task.
- A robot controller not only can be used to control the robot itself but through interfacing with various other equipment can function as a work-cell controller.

2. Actuators :

- Actuators which provide the power to move the joints of a robot are typically *pneumatic, hydraulic* or *electrical devices.*
  - — *D.C. servomotors provide excellent controllability with minimum maintenance requirements.* Torque control is possible by controlling the voltage or current, respectively, applied to the motor. D.C. motors using permanent magnets to generate the magnetic field are a common method of activating a robot joint. *Advantages* offered by such motors include *high stall torque, a small frame size and light-weight and a linear-speed curve which reduces computational effort.*

3. End effectors:

The end effector is considered as special-purpose tooling and is typically customs engineered. A wide variety of end effectors exist to perform different work functions. The various types can be classified into two major groups :

(*i*) Grippers; (*ii*) Tools.

Grippers are used to *grasp and hold objects* whereas ***tools*** can be used to *perform work on a part rather than merely grasp it.*

- "*Grippers*" consist of mechanical devices, magnets, suction devices, adhesives, or other devices to grasp and hold objects. These can be classified as *single* or multiple grippers depending on the number of grouping members attached.

Examples :

— Standard hand ;
— Cam operated hand with inside and outside jaws ;
— Special hand for cartons ;
— Double hand.

4. Sensors :

- Sensors are fundamental in the use of robots and other automated systems. The primary use of sensors can be categorised as follows :
  1. Part inspection for quality control.
  2. Safety monitoring.
  3. Work-cell control interlocks.
  4. Position and related information on parts in a work cell.
- Sensor use in robotics and automated systems includes a wide range of devices. These devices can be divided into the following categories :
  (*i*) Proximity and range sensors.
  (*ii*) Tactile sensors.
  (*iii*) Machine vision.
  (*iv*) Miscellaneous sensors and sensor-based systems.

17.5.7. Types of Industrial Robots

Industrial robots can be broadly *classified* into two main groups as follows :

1. General purpose robots.
2. Special purpose robots.

1. General purpose robots :

- These robots carry standard designs and parts and are readily available.
- They can be easily adapted to the users' requirements by attaching suitable end effectors or fingers to them according to the requirement of the work, such as a part picking operation, welding operation, spray painting, etc.
- Since such robots are mass produced, they are cheaper.

2. Special purpose robots :

- These robots are tailor made to specific job requirements. The ultimate user has to feed his requirements and, based on them, these robots are specially designed and built to cater to

such specific needs. Obviously, their designing and manufacturing consumes a lot of time. As such, they can not be readily available in market.

- Since they can not be manufactured on mass scale, their *prices* are bound to be *higher.*

17.5.8. Terms Related to the Construction and Operation of Robots

The following important terms are commonly related to the construction and operation of robots :

1. Work envelope.
2. Speed of movement.
3. Load carrying capacity.
4. Precision of movement.
5. Drive systems.

1. Work envelope :

- The work envelope is also known as *"work volume"* of a robot. It represents the volume of space around the manipulator arm of a robot, within which it can operate. Since the arm movements in different robot configurations are different; the *work volumes* or *work envelopes* of different coordinate systems are also different.

Example : The work envelopes of cartesian, polar, cylindrical and revolute coordinate system robots respectively will be rectangular, partially spherical, cylindrical and non-uniform or irregular.

2. Speed of movement :

- *"Speed of movement" is the speed at which a robot is capable of manipulating its end effector.* It is governed by the distance to be moved, weight of the part to be moved and the accuracy required in placement of the part in position.
- Heavier parts and higher placement accuracy demands slower movement while the higher parts can be moved at faster speeds.

3. Load carrying capacity :

- The robot's capacity to carry load (weight) varies according to its structure.
- While this capacity for very light models can be as low as 1.5 kg (including the weight of end effector), the heavier class of robots can have their capacities as high as 1000 kg.

4. Precision of movement :

- "*Precision of movement*" is defined *as the degree of precision with which a robot is capable of moving the end point of the wrist of its manipulator arm.*

5. Drive systems :

In majority of robots, *pneumatic, hydraulic* and *electrical drive systems* are used.

- *"Pneumatic drives"* are generally used for *lighter class* and *simpler type of robots, "hydraulic drives,"* for heavier class of robots and *electrical drives* for medium and heavier varieties in which better accuracy and repeatability are used.

17.5.9. Robot programming and languages

In order to programme the work cycle of a robot the following *four methods* are used :

1. Manual programming method.
2. Walk through programming method.
3. Teach pendant method.
4. Off-line programming method.

1. **Manual method:**
- Various controlling components of a robot, like cams, stops, switches, control relays etc., are set through this method.
- This method can be employed only for such robots (with relatively short work cycles) which have to perform simple tasks like *pick and place, loading and unloading* etc.

2. **Walk through programming method :**
- In this method, the arm and hand of the robot are initially moved manually and these movements are stored in computer memory for being followed driving further operations.
- This method suites well for robots used in *arc welding* and *spray painting operations*.

3. **Teach pendant method :**
- It is also known as '*Lead through method*'.
- The 'Teach pendant' is a small control device held in hand. It is used to switch-on power drive for various robot movements in predetermined sequence of motions. The initial robot motion in this case (just like 'walk through method') is also recorded in computer memory and played back during further operations.
- It is *quite an easy and convenient method to use*.

4. **Off-line programming method :**
- Such a programme is separately prepared and fed into the computer memory. Then it is readily available for use whenever the operation is to be performed. Since it is separately prepared, it can be prepared simultaneously while the robot is operating on some other task and, therefore, a lot of time can be saved and the robot can be utilised more.
- This type of robot can be connected to a central CAD/CAM data base system.

Programming languages :
- For first three types of the above methods, no specific programming languages are required.
- Several different languages have been developed through which different robot motions can be effectively controlled. Some of these languages are modifications of the existing common computer languages, while many others are completely new.

Some commonly used computer languages are :

AL; AML; VAL; RAIL; RPL; MCL; HELP.

17.5.10. Intelligent Robots
- A continuous effort is being made to develop control algorithms for reference model hierarchies. Even more intensive efforts have been applied to the development of intelligent controls at the lower levels of the hierarchy, particularly the equipment level. This has lead to concept of intelligent machines or robots. Fundamental issues that need to be addressed include not *only the control structure* but also *sensor strategies, multi-sensor integration or fusion, learning and decision making, programming, mobility and navigation, trajectory planning and overall systems integration.*
- Intelligent robots, as with intelligent factory automation, will provide an abundance of problems and opportunities for industrial engineers. It is anticipated that there will be heightened activity in both theoretical and practical developments in the issues pertaining to the technology and management of such technologies with automated systems.

17.5.11. Applications of Robots

Some common areas of applications of robots are the following :

1. Welding:

- Mostly *spot welding* and *arc welding* in automobile industries.

2. Spray painting:

Robots are used for *spray painting* of automobile bodies. Use of robots for this provides the following *advantages* :

- Higher productivity.
- Substantial saving in consumption of paint.
- Saves human operators from likely health hazards due to toxic fumes and mist, noise, fire etc.
- Consistency of paint layer over the entire surface.
- Saving in energy consumed.

3. Other processing operations

Besides welding and spray paintings, applications of robots are found in number of other processing operations like :

— Polishing ;
— Wire brushing ;
— Riveting ;
— Heat treatment etc.

4. Machine loading and unloading :

Robots are commonly used for loading of stock parts and unloading of finished parts on :

— Die casting machines
— CNC machine tools
— Injection and transfer plastic moulding machines
— Forging presses and hammers
— Stamping and punch presses
— Transfer machines
— Testing machines, etc.

5. Material handling and transfer :

Robots are commonly used for shifting an object from one location to the other. The prominent *areas of application* for this purpose are :

- Transfer of parts from one conveyor to the other.
- Palletising and depalletising.
- Transfer of blanks from an incoming conveyor to the machine tool for further processing.

6. Assembly operations :

Robots find applications in assembly areas involving :

— Screwing of studs and screws in threaded holes;
— Screwing and unscrewing of nuts;
— Insertions of shafts in holes;
— Insertions of electronic components in electronic assemblies;
— Assemblies of small electric motors, plugs, switches, etc.

- So for maximum potential for robot application is observed only in *back type assembly work.*

7. Sorting of parts :

Robots are used to sort out correct parts from a lot of finished parts and place them in proper locations in respective bin.

8. Inspection of parts :

Robots are finding applications, on a fairly good scale, for inspection of finished workpieces and subassemblies, specially of electronic components and devices.

17.6. AUTOMATED GUIDED VEHICLE SYSTEM (AGVS)

17.6.1. General Aspects

- In a flexible manufacturing system (FMS) Automated Guided Vehicles (AGVs) is one of the widely used type of material handling device.
- AGVs *are battery-powered vehicles that can move and transfer materials by following prescribed paths around the manufacturing floor.* They are neither physically tied to the production line nor driven by an operator like a fork lift.
- Such vehicles have *on-board controllers* that can be programmed for complicated and varying routes as well as load and unload operations. The computer for the material handling system or the central computer provides overall control functions such as dispatching, routing, traffic control and collision avoidance.
- AGVs usually *complement* in automated production line consisting of conveyor or transfer systems *by providing the flexibility of complex and programmable movements around the manufacturing shop.*
- The first automated guided vehicle was developed in 1954 by A.M. Barrett.

17.6.2. AGVs Equipment

Several types of equipment, *e.g.*, conveyors, rollers, self-powered monorails, carts, forklift trucks and various mechanical, electromagnetic, pneumatic, and hydraulic devices and *manipulators* can be used to move materials.

- "*Manipulators*" are designed to be controlled directly by the operator, or they are automated for repeated operations, such as loading and unloading parts from machine tools, presses and furnaces. The manipulators are capable of *gripping and moving heavy parts and operating them as required between manufacturing and assembly operations.*
- Machines are often used in a sequence where workpieces are transferred directly from machine to machine.

17.6.3. Applications of AGVs

- In flexible manufacturing system (FMS), industrial robots, specially designed pallets and *automated guided* vehicles (AGVs) are extensively used.
- *AVGs,* which are the latest development in material movement in plants *operate automatically along pathways with in-flow wiring or tapes for optical scanning and without any operator intervention.*
  - This transport system has *great flexibility* and is capable of *random delivery to different workstations.*
  - It *optimises the movement of material and parts in case of cogestion around work-stations, machine breakdown (downtime) or failure of part of the system.*
- The movements of the AGVs are planned so that they interface with *automated storage/retrieval* systems (AS/RS), which utilise workhouse spaces efficiently and reduce labour costs.

17.7. AUTOMATED STORAGE SYSTEMS

17.7.1 General Aspects :

Industrial business firms are presently using traditional (non-automated) systems according to the personnel managing and budgetary considerations available to them. These storage systems include :

(*i*) Bulk storage system; (*ii*) Rack storage system;
(*iii*) Shelves and bins; (*iv*) Drawer storage system etc.

- The above systems require human labour to access for storage (which is *static*).
- In *highly 'automated system' loads are entered and retrieved by computer controls without any human participation except for input or control.*
- Automated systems have one *disadvantage* that they require *large investment and change in style of working.*

17.7.2. Objectives of Automated Storage Systems

The automated storage systems have the following *objectives* to serve :

1. To improve stock rotation.
2. To improve security.
3. To increase capacity to store.
4. To increase storage density.
5. To recover factory or warehouse floor space which is used for storing work in process.
6. To reduce pilferage and provide safety to stores.
7. To reduce labour costs.
8. To improve customer service.

17.7.3. Automatic Storage/Retrieval Systems

- This type of storage system allows the user to do store and retrieval operations with *speed and accuracy.*
- An AS/RS system consists of one or more aisles and each is serviced by storage retrieval machine. The aisles have storage racks for holding the stored materials.
  — The retrieval machine can be crane or any other type.
  — Each aisle of AS/RS is provided with one or more input/output stations (also referred as pick up/delivery station) where material is delivered for storage and picked up. These input/output stations are computer controlled or manually operated or can be interfaced with any automated handling system.

Types of AS/R systems. Various types of AS/R system are enumerated and discussed as under :

(*i*) Unit load AS/R system (*ii*) Deeplan AS/R system
(*iii*) Miniload AS/R system (*iv*) Man on board AS/R system
(*v*) Automated item retrieval system (*vi*) Vertical lift storage/retrieval system.

(*i*) **Unit load AS/R system :**

- It is typically a large automated system to handle unit load stored on pallets or in containers.
- The system is computer controlled.

(*ii*) **Deeplan AS/R system :**

- It is high density unit load storage system which is used when large quantities of stock is to be stored but number of separate stock racks is small.

- This system stores ten or more loads in a single rack, are behind the next. Each rack is designed for flow with input on one side and output on another side.

(*iii*) **Miniload AS/R system :**

- In this storage system small loads are handled that are contained in bins or drawers.
- The S/R is specially designed to retrieve the bin and deliver it to output station at the end of aisels, so that individual item can be withdrawn from the bins. The bin or drawer must be retrieved back to its position or location.

(*iv*) **Man on Board AS/R system :**

- In this system, a human operator, rides on the carriage of the machine (S/R) while the miniload system delivers an entire bin to the end of aisles pick station. The bin or container is then returned to its position in compartment.
- The man on board permits individual items to be picked directly at their storage locations.

(*v*) **Automated item retrieval system :**

- In this system, items are stored in lanes than bin or drawers.
- Any item to be retrieved is pushed from its lane and dropped into a conveyor for delivery.

(*vi*) **Vertical lift storage/retrieved system :**

- In this system a centre aisle is used to access loads in vertical position.
- Vertical lift, storage modules with heights of 10 m or more are capable of holding large inventories and help in saving floor space.

Applications of AS/R system

Following are the applications of AS/R system :

1. Warehouse and distribution systems.
2. Storage of raw materials.
3. Work-in-process manufacturing
   — Computer control and tracking of materials;
   — Buffer storage in production;
   — Support in JIT;
   — Knitting of parts for assembly.

QUESTIONS WITH ANSWERS

Q. 17.1. In what ways a robot differ from a NC machine tool ?

Ans. A robot differs from a machine tools in the following respects :

1. As compared to a NC machine tool, a *robot is a lighter and more portable equipment.*
2. *Programming* of a robot is different from the *tool programming* used in NC machine tools.
3. The applications of robots are more general in nature as compared to a NC machine tool.

Q. 17.2. Give the companion between 'Automated machine' and 'Robot'.

Ans. The comparison between 'Automated machine' and 'Robot' is as follows:

S.No.	Aspects	Automated machine	Robot
1.	*Type of job*	It performs a particular job only in the designed sequence.	It can be made to do different jobs at different times and in different sequences.
2.	*Programming*	It cannot be programmed.	It can be programmed to change the sequence of tasks.
3.	*Knowledge base, intelligence*	It has neither a knowledge base nor intelligence.	It is possible to impart intelligence base by suitable programming technique.

Q. 17.3. Discuss briefly the 'motion systems' used in industrial robots.

Ans. The following two types of *motion systems* are used in *industrial robots* :

1. Point to point system.
2. Continuous path system.

1. Point-to-Point system :

- In this system, only the movement of robot from one point location to other location in space is controlled with no regard to the path followed by it in doing so.
- Majority of the robots employed in production activities, like *pick and place*, *loading and unloading of parts* etc. work on Point-to-point motion system.

2. Continuous path system :

- In this system a robot follows a predetermined *path* or *contour* in reaching from one point to the other.
- These robots need higher level of memory and control as composed to Point-to-point robots.
- Such robots are widely required in several operations like *continuous welding*, *spray painting* etc.

Q. 17.4. Discuss briefly "Robot sensing and sensors."

Ans. In order to impart more and more artificial intelligence to a robot, in order to bring its operation nearer to that of a human being, efforts continue to be made for improving its *sensing abilities, i.e.*, its vision, hearing, feeling by touching other objects, vision and coordination between its hand and eye. These objectives are achieved by using different types of *sensors*. These sensors may be of :

— Digital type or analog type;
— Contact type or non-contact type;
— Visual type or non-visual type, etc.

Sensor may be *Internal State Sensors* and *External State Sensors*.

• ***Internal State Sensors.*** These are used for *measuring position, velocity and acceleration of the end effector or the joints of a robot.* This class of sensors includes devices like :

— Linear inductive scales;
— Synchronous;
— Resolvers;
— Potentiometers;
— LVDTs, RVDTs;

— Optical encoders;
— Tachometers etc.

- ***External State Sensors.*** These sensors *determine the relationship of the robot with its environment and the objects handled* by it. Some of the devices used for this purpose include :

— Proximity devices;
— Electromagnetic sensors;
— Strain gauges;
— Ultraviolet sensors.
— Pressure transducers, etc.

All these are *non-visual* sensors and enable sensing of force, torque, obstruction, distance from an object, touch, slip, etc.

The *visual external state sensors* includes a video camera with a programmed computer and a source of light. With the help of this sensing unit a robot is able to sense the presence, position and orientation of an object in the line of its vision within its work volume.

Q. 17.5. Discuss briefly "Workcell and Interlocks".

Ans. Workcell :

- The term ***workcell*** *represents a collection of automated equipment and controls that acts as a means to coordinate all the activities within the robot workstation.* It is required because the robot system by itself has a very limited utility. In order to utilise it for performing some really useful tasks, it has to be integrated with many other things like work parts, part feeders, conveyors, control devices, process machinery, tools, machine tools etc.
- A work cell need not essentially cover a single robot only, but may contain several robots. In a robot "*work station*", some of the activities take place in a sequence and some others occur simultaneously. A controlling device, called a *"workcell controller" or "workstation controller"*, is, therefore suitably incorporated, which coordinates and regulates these different activities and ensures that they are performed in a proper sequence.

Interlocks:

- In *workcell control,* there has to be some means to check the continuation of sequence of the work cycle whenever needed. The means used to apply this check is known as an "*Interlock*".
- The workcell carries *two types facilitates of interlocks* – one "*outgoing*" and the other "*incoming*". The provision of interlocks facilitates an effective control over the workcycle by permitting the sequential activities to take place only when they should and preventing them when they should not.

Q. 17.6. What are the advantages of using 'Automated Guided Vehicle System (AGVS)' in 'Flexible Manufacturing System (FMS)' ?

Ans. Following are the *advantages* of using AGVS in FMS.

1. Flexibility.
2. Real time monitoring and control.
3. Safety.

1. Flexibility :

- The route of AGVs can be easily altered and modified, simply by changing the guide path of the vehicles. This is more *cost effective* than modifying the fixed conveyor line or rail guided vehicles.
- It provides a *direct access* material handling system for loading and unloading FMS cells and accessing the automated storage and retrieval system.

2. Real time monitoring and control :

— AGVs can be monitored in real time because of the computer control. If the FMS centre system decides to change the schedule, the vehicles can be re-routed and urgent requests can be served.

— *AGVs are usually controlled through wires implanted on the factory floor using a variable frequency approach.*

3. Safety :

- AGVs can travel at a slow speed but typically operate in the range 10 to 70 m/min. They have *on-board microprocessor control* to communicate with the local zone controllers which direct the traffic and prevent the collision between vehicles as well as the vehicle and other objects.
- AGVs may also incorporate :
  — Warning lights;
  — Fire safety interlocks;
  — Controls for safety in shops.

Q. 17.7. Explain briefly how you can achieve vehicle guidance, routing and traffic control in a manufacturing plant employing AGVs.

Ans. The conventional conveyor systems are sometimes inadequate to fulfil the requirements of plants where production is carried out through interconnected work cells and where flexibility and rapid change-over times are of chief importance. Automated Guided Vehicles (AGVs) offer a variable solution for such needs.

- **AGVs** *possess intrinsic flexibility and capability of synchronous operations and easiness of integration with other automatic devices like robots, CNC, automatic storage/retrieval systems.*
- AGVs are designed for *automatic, efficient and flexible execution of transport tasks* in which a variety of loads (workpieces, fixtures, empty pallets, tool dispensers) have to be transported at regular intervals with varying frequencies and from a fairly large number of locations (input/output stations set-up areas, machining centres and auxiliary machines, wait stations and storage areas).

HIGHLIGHTS

1. *Sensors* translate some variable on the machine or process to a signal (usually electrical) that can be subsequently processed by the control equipment to obtain the current value of the variable of interest.
2. *Actuators* accept a signal from the control system and in some fashion impose this signal on the machine or process being controlled.

3. The *mechanisation* is the transfer of skills and manual activities to machine operations.
4. *Mechatronics* has been described as "the union of mechanical and electronic engineering needed in producing the next generation of machines, robots and smart mechanisms for applications such as manufacturing, large-scale construction and work in hazardous equipment".
5. An *"Industrial robot"* is a reprogrammable multi-functional manipulator designed to move materials, part tools, or special devices through variable programmed motions for the performance of a variety of tasks.
6. Industrial robots are of two types :
   (*i*) General purpose robots.
   (*ii*) Special purpose robots.
7. The following four methods are used to programme the work cycle of a robot :
   (*i*) Manual programming method.
   (*ii*) Walk through programming method.
   (*iii*) Teach pendant method.
   (*iv*) Off-line programming method.
8. *Automated Guided Vehicles (AGVs)* are battery-powered vehicles that can move and transfer materials by following prescribed paths around the manufacturing floor.

OBJECTIVE TYPE QUESTIONS

Fill in the blanks, say 'Yes' or 'No' :

1. It is said that CIM has .... percent computer technology and .... percent is the business process and people.
2. Automated production systems can be put into three groups : .... automation, programmable automation, flexible automation.
3. .... automation is most suitable for mass/flow production.
4. In programmable automation there is a high flexibility to deal the changes in product configuration provided the differences are not dramatic.
5. .... automation is basically an improvement upon programmable automation.
6. Flexible automation is not suitable for planned work-load.
7. Flexible automation can produce various combinations and schedules of products and does not require batch production.
8. .... programming is concerned with the planning and documentation of the sequence of processing steps to be performed on a numerical control machine.
9. Automatically Programmed Tools (APT) is a programming language which allows geometrical data to be specified together with tool motion statements for any NC material processing machine.
10. An industrial .... may be defined as 'a reprogrammable multi-functional manipulator designed to move material, parts, tools or other specialised devices through variable programmed motion for the performance of a variety of task'.

11. Basically the robot needs .... axes of motion (or degrees of freedom) to reach a point with a specific 'orientation' in the space.
12. An industrial robot has three types of components : Physical parts or anatomy, built in instruction or instinct (placed there by the manufacturer) and learned behaviour or task programmes (on-the-job training).
13. The .... is the part of the robot that physically performs the task.
14. The .... is the brain of the robot.
15. Robot .... is concerned with the physical construction of the body, arm and wrist of the machine.
16. The polar configuration robot uses a telescopic arm that can be raised or lowered about a horizontal pivot.
17. The .... configuration robot uses a vertical column and slide that can be moved up or down along the column.
18. The cartesian coordinate robot uses three perpendicular slides to construct the x, y and z axes.
19. The cartesian configuration robot can reach out only in front of itself.
20. The joints used in the design of industrial robots can be classified in two categories : Linear joints and .... joints.
21. Work envelope refers to the space within which the robot can manipulate its wrist end.
22. The .... system of a robot is used to power a robot and moves its body, arm and wrist.
23. Limited-sequence robots make use of servo-controlled system to indicate relative positions of the joints.
24. Playback robots with point-to-point control use a more sophisticated system where in a series of positions or motions are 'taught' to the robot, recorded into system memory, and repeated by the robot under its control.
25. Robots with continuous path capability are used for works such as spray painting, arc welding etc.
26. .... robots are generally recommended for simple applications such as pick-and-place operations.
27. .... robots constitute a growing class of industrial robots that possesses the capability to interact with the working environment in a way that seems intelligent.
28. The speed of response and .... are two important characteristics related with the dynamic performance of the robot.
29. One of the important aspects of the robot's performance is the .... of its movements.
30. .... of a robot refers to its ability to position its wrist end at a desired target position within the work volume.
31. .... defines Robot's capability to position its wrist or end effector at a point in space that had previously been taught to the robot.
32. The robot cannot be used in production while it is being programmed.
33. Lead through programming is compatible with modern CAD/CAM and other information processing systems.

34. Lead through programming is difficult for complex robot movements.
35. Most of the robot languages in use today are a combination of textual programming and .... programming.
36. The first generation robot languages use a combination of compound statements and teaching box procedures for developing robot programmes.
37. The .... language is an example of first generation robot programming language.
38. The second generation robot languages are also called "Structured Programming Languages" because they are similar to computer languages.
39. .... technology is an approach to the organisation of work in which organisational units are relatively independent groups and each group of machines or facilities is responsible for production of a given family of product(s).
40. *Part-family* is defined as 'Collection of parts which are similar in terms of geometric shape, size and similar processing steps required in manufacturing, so that flow of materials through the plant improves'.
41. Factory Flow Analysis (FFA) is the first level of planning in progressive production flow analysis.
42. Live analysis is the final level of planning in Production Flow Analysis (PFA).
43. Numerical Control (NC) is the least sophisticated form of automatic control of machine tools.
44. *Part-family programming* is an NC programme system that groups common or similar programmes for machining of part families into a major computer programme which is a permanent base from which an NC tape can be prepared for any part in the part-family.
45. Travel heart handles a large quantity of material handling data in a concise and rapid way.
46. .... analysis is based upon the sequence of operations for parts and products.
47. Systematic layout planning is analysing the relative relationships between various workcentres.
48. Machine loading and product mix decisions are not important in group technology.
49. The problems of distributing the work-load amongst the facilities/work-centre is referred to as *Machine loading problem.*
50. .... *manufacturing system* (FMS) is a manufacturing system based on multi-operation machine tools, incorporating integrated computer control with associated support function and material handling.

ANSWERS

1. 20, 80	2. Fixed	3. Fixed	4. Yes	5. Flexible	6. No
7. Yes	8. NC	9. Yes	10. robot	11. six	12. Yes
13. Manipulation	14. controller	15. anatomy	16. Yes	17. cylindrical	
18. Yes	19. Yes	20. rotational	21. Yes	22. drive	23. No
24. Yes	25. Yes	26. Limited-sequence		27. Intelligent	
28. stability	29. precision	30. Accuracy	31. Repeatability		32. Yes
33. No	34. Yes	35. teaching box	36. Yes	37. VAL	38. Yes
39. Group	40. Yes	41. Yes	42. Yes	43. No	44. Yes
45. Yes	46. Sequence	47. Yes	48. No	49. Yes	50. Flexible

THEORETICAL QUESTIONS

1. Discuss briefly "Mechanisation and automation".
2. What is the difference between "microautomation" and "macroautomation" ?
3. How "Automated production systems" are classified ?
4. Explain briefly the following :
   (*i*) Fixed automation (*ii*) Programmable automation
   (*iii*) Flexible automation.
5. How is "Industrial Robot" defined ?
6. What are the objectives of using industrial robots ?
7. What are the advantages of employing robots ?
8. Explain briefly with a neat sketch the main components of a robot.
9. Explain briefly any four of the following robot components:
   (*i*) Base (*ii*) Manipulator arm
   (*iii*) Gripper or effector (*iv*) Drives
   (*v*) Controller (*vi*) Sensors.
10. Discuss briefly the six basic motions or degrees of freedom of a robot.
11. Explain briefly the classification of 'robot'.
12. Discuss briefly the following basic configurations of industrial robots :
    (*i*) Polar configuration (*ii*) Cylindrical configuration
    (*iii*) Cartesian coordinate configuration (*iv*) Jointed-arm configuration.
13. Explain briefly the following is relation to an industrial robot :
    (*i*) Controller (*ii*) Actuators
    (*iii*) End effectors (*iv*) Sensors.
14. Discuss briefly the following types of industrial robots :
    (*i*) General purpose robots (*ii*) Special purpose robots.
15. Explain briefly the following terms related to construction and operation of robots:
    (*i*) Work envelope (*ii*) Speed of movement
    (*iii*) Load carrying capacity (*iv*) Precision of movement
    (*v*) Drive systems.
16. Discuss briefly the following methods used to programme the work cycle of a robot.
    (*i*) Manual programming method (*ii*) Walk through programming method
    (*iii*) Teach pendant method (*iv*) Off-line programming method.
17. Write a short note on "Industrial Robots".
18. What are the applications of robots? Explain.
19. What do you mean by AGVS? Explain.
20. Discuss briefly AGVS equipment.
21. State the applications of Automated Guided Vehicles (AGVs).
22. What do you mean by "Automated storage systems"? Explain.
23. What are the objectives of Automated storage systems?
24. Explain briefly the various types of Automatic storage/retrieval systems.
25. List the applications of Automatic storage/retrieval systems.

18

Product and Process Design for Integration

18.1. Product analysis, 18.2. Concepts of process and job, 18.3. Strategies for integrated product and process design, 18.4. Tools and methods, 18.5. Concurrent engineering, ***Questions with Answers—Highlights—*** *Objective Type Questions—Theoretical Questions.*

18.1. PRODUCT ANALYSIS

The product which is to be manufactured is first analysed primarily from a technological point of view to determine the processes required.

Assembly charts :

- For visualising the material flow and the relationship of parts, *schematic and graphic models* are commonly developed.
- The "*assembly chart*" can be useful in making preliminary plans regarding subassemblies, where purchased parts are used in the assembly sequence, and appropriate general methods of manufacture. The assembly chart is often called a "***Goznito chart***" for the words, "goes into".

Operation process chart:

- Presuming that the product is already engineered, we have complete drawings and specifications of the parts, their dimensions and tolerances, and materials to be used.
- The engineering drawings specify locations, sizes, and tolerances for holes to be drilled and surfaces to be finished for each part.

With this information, the most economical equipment, processes, and sequences of processes can be specified.

- An *operation process chart is a summary of all required operations and inspections.* It is a *general plan for manufacture.*

Although the focus of such charts is on the technological processing required, it is obvious that the jobs to be performed by humans have also been specified. Some discretion in the make up of jobs still exists, especially, in the assembly phase; however, it is clear that technology is in the saddle.

18.2. CONCEPTS OF PROCESS AND JOB

The technology imposes constraints that limit the possible arrangement of processes and jobs; the job satisfaction and social system needs impose also certain constrains.

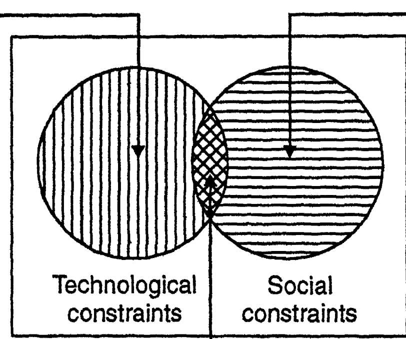


Fig. 18.1. Feasible solution spaces for technological and social systems, and joint solution space.

— The circle marked "Technological constraints" in Fig. 18.1. indicates that all job designs within the circle represent feasible solutions from a technological point of view, and all points outside the circle are infeasible.

— Similarly, the circle marked "Social system constraints" indicates that all designs within that circle represent feasible solutions from the socio-job satisfaction point of view.

— Within the shaded area of overlap between the two circles, we have a solution space that *meets the constraints of both technology and the social system. The shaded area defines the only solutions that can be considered as feasible in joint terms.* Our objective, then is to consider jointly the economic and social system variables, and find the *best solution.*

- *Because optimisation is an unclear process in job design, we seek solutions that are acceptable.*

18.3. STRATEGIES FOR INTEGRATED PRODUCT AND PROCESS DESIGN

In view of extreme competitive pressure, the general aims in the entire process of manufacturing are to reduce the cycle time from product concept to market by fifty percent, reducing costs by similar amounts while increasing quality—but particularly to give early visibility to many downstream options *at the product concept level,* thus reducing risk.

To accomplish these aims, *a team is assembled* and applied on the next new or redesigned product that the company is planning. The '*advantage*' of this method is that it can be implemented instantly with your present people without the necessity of investing a single piece of new technology (computers, FMS etc). The investment is in people, that is, *changing their awareness by training.* Teams are then formed with designers, manufacturers, suppliers, and users. The '*limitation*' with this technique is that it presents many institutional-social problems to management;

— how individual team members resolved their carrear issues;

— what happens to them when they leave the team and return to their old organisations;

— the use of outside "facilitators";

— what types of training are needed for staff, for management and so on.

- This larger strategy attempts to apply all the typical downstream activities at the *product concept level.* It is called "*Concurrent Engineering (CE)*" or "*Concurrent Design (CD)*" or "*Integrated product and process design*" or "*Simultaneous engineering*" or "*Integrated system management*". On a higher level, which seeks to integrate all the activities of the company, it is called "Enterprise Integrated Framework (EIF)".

Following are the *three levels* of applications:

- ***First level.*** It involves a *management decision* to integrate all the normal serial operations into an integrated team. The approach is very effective. However, there is no long-term competitive advantage.
- ***Second level.*** It involves the *use of new tools and methods* (a number of them computer based) to aid this process by giving quantitative visibility to options, and constraints due to economic-technological issues.

  It is generally the approach used by companies after they have tried a few projects using the first method and realise that new tools and methods may be helpful to alleviate some of the problems associated with the integrated team only concept.
- ***Third level.*** This level represents the *integration of these various tools into a feature-based design system* involving :

  — solid models;

  — extensive databases with analysis tools for process planning;

  — scheduling;

  — economic modelling;

  — automatic system design.

18.4. TOOLS AND METHODS

- A number of tools, methods, and techniques have been developed *to help assembly or manufacturing system designers.*
- Some of the ***"new tools"*** available are :

  — Part-mating science;

  — Liaison sequence analysis;

  — System synthesizing techniques;

  — Programs capable of automatically generating process plans and task-resource matrix needed to automate the generation of the system synthesizing technique.

These tools were developed primarily to support assembly system design but their potential use is much broader.

Part-mating science:

- This is an analysis technique for specifying the engineering requirements for physically mating piece parts, both rigid and spring parts.

Assembly System Design Program (ADSP) :

- This is a *computer program based on dynamic programming* with heuristics capable of synthesizing manufacturing systems based on economic-technological issues created from a process plan, technical resources including people and constraints.
- It does not simultate a system that you have given it, it creates completely new systems based on a detail description of the problem, resources and constraints.

Fig. 18.2 shows a simplified block diagram of the system.

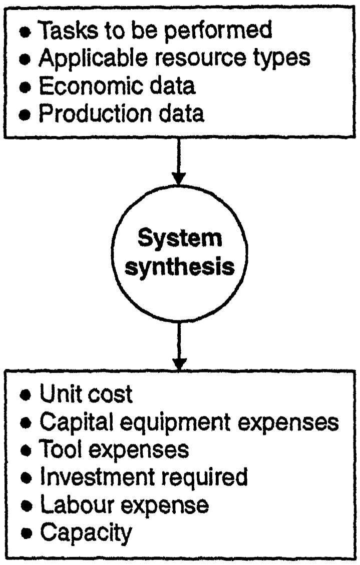


Fig. 18.2. Simplified block diagram of an assembly system design program (ASDP)

SPM (Assembly sequence, Assembly process plan and Assembly task resource matrix):

- This is a method for *automatically generating the necessary process plan and task-resource matrix* needed by ASDP starting from a simple bounding-box description of the individual piece-part and data on the part mates.

Liaison Sequence Analysis (LSA) :

- This is a method for *identifying all possible ways to assembly a product* starting from liaisons between parts, where a liaison may be a process, a test, or the physical mating of two parts.
- A typical industrial engineering study might identify one or at most two ways of assembling something; LSA will show *all possible ways* by which something can be assembled. The results of LSA can then be correlated with reliability modelling and economic-technological analysis to obtain the best product quality for a certain capital investment.

Integration of tools :

- The tools listed can be used individually, as a group, or as an integrated set. They have been applied individually on studies ranging from precision mechanisms to an automation strategy for shipyards.
- *Basically the tools are generic and thus independent of the product domain.*

Feature-Based Design (FBD) Systems :

- *Feature-based design captures design intent* (assembly topology, product-function, manufacturing, or field use) *while creating part and product geometry.*
- Design for assembly, as used here, extends existing ideas about critiquing part shapes and part count to include assembly process planning, assembly sequence generation, assembly fixturing assessments and assembly process costs. As used here, features are not restricted to

the set required to accomplish the machining of an individual part, they may describe attributes to enable piece-part manufacture, or describe a process, or define some form of testing.

18.5. CONCURRENT ENGINEERING

Concurrent engineering (also known as '*Simultaneous engineering*') *is an approach used in product development in which the functions of design engineering, manufacturing engineering and other functions are integrated in order to reduce the required time to bring a new product in the market.*

Earlier approach of launching a new product, with two functions, "*Design*" and "*Manufacturing*" tend to be separated. The design development team develops new design sometime without much consideration given to the manufacturing capabilities of the company. There is little opportunity for manufacturing engineers to offer advice how the design might be altered to make it more manufacturable. *In constant* a company practicing concurrent engineering, *manufacturing engineering department also becomes involved in the product development cycle,* providing necessary advice how the product and its components can be designed to facilitate manufacture and assembly. It also offers the early stages of manufacturing planning of the product.

- Concurrent engineering, besides manufacturing, involves other functions of product development cycle such as :
  — Quality;
  — Field service;
  — Vendors supplying critical components, etc.
- Concurrent engineering includes several *elements* such as :
  — Design for manufacturing and assembly;
  — Design for quality;
  — Design for life cycle;
  — Design for cost.

QUESTIONS WITH ANSWERS

Q. 18.1. Discuss briefly "Technological view of process planning and job design".

Ans. The technological view of process planning and job design is briefly discussed as under :

- **"Process planning"** takes as *input* the *drawings* or *other specifications* that indicate what is to be made and the forecasts, orders, or contracts that indicate the *quantity* to be made.
- The *drawings* are then analysed to determine the overall scope of the project. If it is a complex assembled product, considerable effort may go into "exploding" the final product into implied component parts and subassemblies. This overall planning may take the form of special drawings that show the relationship of parts, cutaway models, and assembly drawings.
- Preliminary decisions are made concerning some assembly groupings to determine which parts to make and buy as wells as the general level of tooling expenditures. Then for *each part, a detailed routing through the system is developed.* Technical knowledge is required concerning processes, machines and their capabilities, cost and production economics. Ordinarily, a range of processing alternatives is available. The selection may be influenced strongly by the projected volume and stability of product design.

Q. 18.2. Discuss briefly "Process-job design in relation to layout".

Ans. Following are the two basic types of physical systems :

(*i*) Process focused system;

(*ii*) Product focused system.

Although many actual systems are combination of these two extremes, the two types illustrate the nature of jobs that result.

— At one extreme, where *product volumes are low and variety flexibility and quality are the prime strategies*, the economical production system will be **functional layout**. Such a solution to the layout of physical facilities results in relatively good utilisation of equipment by time sharing it for various jobs requiring a certain production technology.

— At the other extreme, for products that are *standardised and produced in high volume*, there is little if any difference in process requirements, from unit to unit. Specialisation in the form of **linear or product layout** is *economically justified.*

Between the extreme, we find mixed types of layout.

- The appropriateness of a given layout in supporting the competitive strategy depends on *economics of alternate solutions.*

Examples. If plant, equipment, and other resources were *costless,* we would setup separate product-focused facilities for each product. Each product would have its own production line. Because these factors of production are *not free*, *we must have sufficient utilisation of facilities* to justify "single-product" lines.

— For an "*oil refinery*" or a steel mill, a *very high utlisation* is important because of the immense capital requirements,

— For a "*fast-food operations*", perhaps *fifty per cent utilisation is sufficient.*

Q. 18.3. Explain briefly "Functional layout for process-focused systems".

Ans. *In functional layout*, the processing units are organised by functions on the assumption that certain skills and expertise are available in that serve facility.

In practice, many examples of process-focussed systems can be found, for instance:

— Manufacturing;

— Hospital and medical clinics;

— Large offices;

— Municipal services;

— Libraries.

In every situation, the work is organised according to the *function performed.*

- The *machine shop* is one of the most common examples, and the name and much of our knowledge of process-focussed system results from the study of such manufacturing system.

Q.18.4. What is CIM? List some of the technologies of CIM.

Ans. • **Computer integrated manufacturing (CIM)** *is the automation of the entire manufacturing process with computers.*

— Designing a CIM system means applying systems thinking to the manufacturing enterprise; in brief, it means viewing the organisation as a unit with certain inputs and certain desired output and designing systems that are both *computer-based and people-integrated to cause the inputs to be transformed into the outputs.*

- Some of the technologies of CIM include :
  (*i*) Computer-aided design.
  (*ii*) Numerical control.
  (*iii*) Robotics.
  (*iv*) Expert systems.
  (*v*) Automatic guided vehicles.
  (*vi*) Computer-aided testing.
  (*vii*) Automatic assembly.
  (*viii*) Communication networks.
  (*ix*) Remote sensing.
  (*x*) Digital instrumentation.

Q. 18.5. Discuss briefly the components of "Computer Integrated Manufacturing (CIM)".

Ans. The components of CIM are discussed below :

1. **Computer-aided design and drafting (CADD) :**

- CADD has evolved from drafting automation. Automated drafting systems simpl ying many aspects of its creation.
- The engineering portion of a CIM organisation must use computer-aided *design*, nc computer-aided drafting and must product three-dimensional geometric data.

— The three-dimensional geometric data can take three common forms: *Wire fran e, surfaces* and *solids*, in order of progressively diminishing abstraction.

2. **Computer-aided engineering (CAE) :**

- It is the term used to describe computer-based engineering analysis of *digital models.*
- The most popular form of CAE for *mechanical engineers is finite-element analysis.* In *electronics,* there are *various forms of circuit analysis* that are applied in this manner.
- For CIM to be efficient, the model created in the computer-aided design process should be able to be digitally tested, through the design verification process that follows initial design.

3. **Computer aided manufacturing (CAM) :**

- It usually refers to *numerically controlled machine tools,* the means of controlling them and the associated computer-based systems within the factory.
- This category also includes other physical devices such as :
  — Flexible machining system (FMS);
  — Robots;
  — Automatic guided vehicles (AGVs); and
  — Data control systems, such as manufacturing requirements planning (MRP) software.

4. **Data base management systems (DBMS) :**

- CIM, is in a sense, *data based manufacturing.*
- A robust CIM data base must be equally efficient with graphical and non-graphical data. Recent developments in data base management technology have made the implementation of CIM easier than before.

5. **Networks :**

- Networking is the most important technology for CIM: The digital connectivity that allows the data to flow from design through production to field support and back is key to the "integrated" aspect of CIM.

- Salient features of networks include :
  - Topology;
  - Physical media;
  - Protocols;
  - Bandwidth;
  - Cost.
- Popular networking schemes include :
  - *Token ring* and *collision sensing* protocols;
  - Ring and star topologies;
  - *Coal and twisted-pair physical media.*

6. Computational hierarchies:

- In addition to the engineering workstations and servers, the engineering data management network and accounting computers, many other computers serve the CIM organisation. Most of them are *programmable logic controllers,* or PLCs, simple computers designed for integration into industrial systems and therefore offering a particularly a wide range of input-output options, as well as a variety of robust installation possibilities.

Q. 18.6. List the points in regard to design for economy in mass production.

Ans. The head of the design organisation must be part of or have direct access to company's .ɔp management. The design organisation must have direct links with those responsible for production, purchasing and marketing functions.

Following points need be considered in regard to *design for economy in mass production* :

1. Before taking up the design, the designer must be given precise and comprehensive terms of reference. Some formal procedure should be there to avoid wastage of time upon ill-conceived ideas.
2. Adequate time must be given to designer to arrive at optimum solution for a given problem. This can mean considerable cost savings later on.
3. Designer must have fairly good idea of production techniques. The design of product and selection of manufacturing process must proceed in parallel.
4. Process selection is of paramount importance.
5. Good detail design is of vital importance and may also be critical to the cost of manufacture, quality and reliability of the product.
6. Simplicity should always be aimed for.
7. If design can't be produced at a cost which will permit it to be sold at a profit, then it is as much a failure as if it did not function correctly.
8. Great savings in manufacturing, stocking and disturbing can be made by standardisation and variety reduction.
9. The quality and reliability of the design must be right.
10. Simplification, specialisation and standardisation can bring handsome rewards.

Q. 18.7. Discuss briefly 'Generic CIM architecture'.

Ans. CIM involves a great many functions within an organisation. The complexity of this relationship is illustrated in Fig. 18.3.

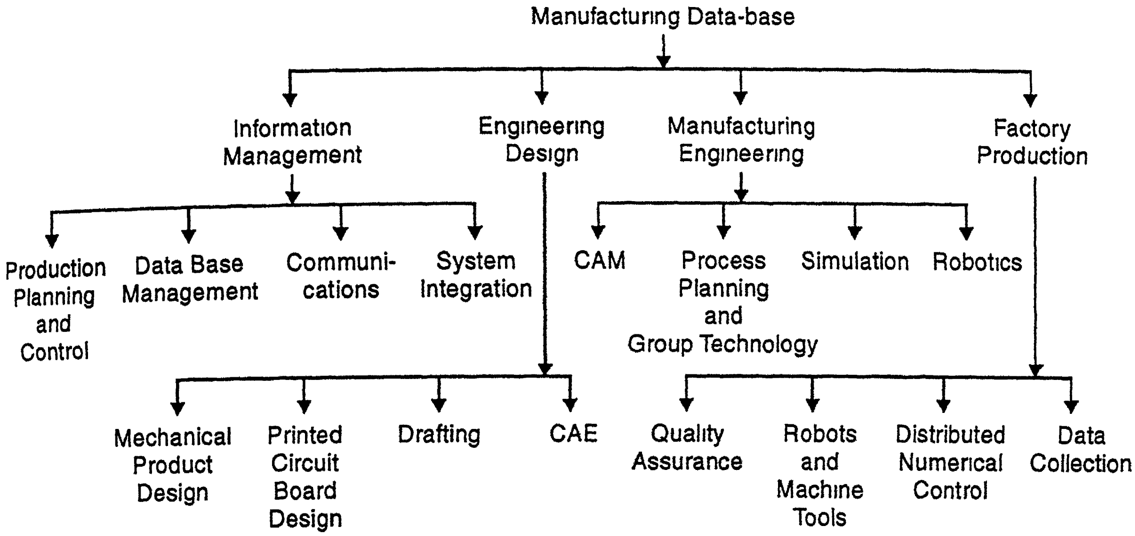


Fig. 18.3. Generic CIM architecture

HIGHLIGHTS

1. *Part-mating science* is an analysis technique for specifying the engineering requirements for physically mating piece parts, with rigid and spring parts.
2. *ADSP (Assembly system design program)* is a computer program based on dynamic programming.
3. *Feature-based design* captures design intent while creating part and product geometry.
4. *Concurrent engineering* is an approach used in product development in which the functions of design engineering, manufacturing engineering and other functions are integrated in order to reduce the required time to bring a new product in the market.

OBJECTIVE TYPE QUESTIONS

Fill in the Blanks or Say 'Yes' or 'No':

1. EIF stands for Enterprise Integrated Framework.
2. CD means .... design.
3. .... science is an analysis technique for specifying the engineering requirements for physically mating piece parts, both rigid and springs parts.
4. ASDP is a computer program based on .... programming.
5. .... is a method for identifying all possible ways to assemble a product starting from liaison between parts, where a liaison may be a process, a test, or the physical mating of two parts.
6. Feature-based design captures design intent while creating part and the .... geometry.
7. .... is the automation of the entire manufacturing process with computers.
8. Designing a CIM means applying systems thinking to the manufacturing enterprise.

9. A well-designed CIM-based factory can have a breakdown point of about 70 percent of its operating capacity.

10. Computer-aided design in one of the technologies of CIM.

ANSWERS

1. Yes	**2.** concurrent	**3.** Part-making	**4.** dynamic	**5.** LSA	**6.** product
7. CIM	**8.** Yes	**9.** No	**10.** Yes.		

THEORETICAL QUESTIONS

1. Explain briefly the following :
   (*i*) Assembly charts.
   (*ii*) Operation process chart.

2. Discuss briefly "Concepts of process and job".

3. Discuss briefly the strategies for integrated product and process design.

4. Discuss briefly the following tools :
   (*i*) Assembly System Design Program (ADSP).
   (*ii*) Liaison Sequence Analysis (LSA)
   (*iii*) Feature-based design systems.

5. Write a short note on "Concurrent Engineering".

□□□

19

Computer Aided Process Planning

19.1. Introduction, 19.2. Analysis and planning data required, 19.3. Analysis and planning steps and considerations, 19.4. Process format and content, 19.5. Computer aided process planning (CAPP) systems, ***Questions with Answers****—Highlights—Objective Type Questions—Theoretical Question.*

19.1. INTRODUCTION

- The manufacturing activities necessary to accomplish the production of an end product must be processed or arranged in an orderly, worktable sequence. *This analysis and planning is the bridge between design engineering and product manufacturing.* It encompasses every phase of industrial and manufacturing engineering by establishing a manufacturing plan which is economical and supplies a quality product.
- *Process analysis and operation planning are required for all manufactured products regardless of their size, material make up, or type of construction.*
- An adequately defined operation plan can improve any task which adds value to a product with materials, labour power, or equipment. The detail and complexity of process plan will vary greatly from simple handwritten notes to detailed CAD/CAM-created points and computer-generated procedures specifying parts, tools and equipment, gauges and their readings, and even which hand is employed for each movement.
- The personnel performing process analysis and operation planning are in a pivotal position between product engineering and manufacturing operations. They receive product information from design engineering, interpret the data into terms of process requirements, and then create operation plans with work standards and tooling requirements for manufacturing to use.

19.2. ANALYSIS AND PLANNING DATA REQUIRED

The amount of detailed desired in process analysis and operation plan will determine the volume and scope of data necessary. The following are the examples of the type of *data required for effective operations plqns:*

1. Part drawings and bills of material.
2. Expected product life and manufactured quantities.
3. Equipment list.

4. Work centre load forecasts.
5. Material specifications.
6 Speed and feed data.
7. Tooling and gauging standards and inventory.
8. Work measurement and standard data.
9. Abbreviation listing.
10. Scrap and rework history.
11. Cutting fluid applications.

19.3. ANALYSIS AND PLANNING STEPS AND CONSIDERATIONS

The sequence of events necessary to establish an effective manufacturing process varies from company to company and depends upon plant size and the product manufactured. Companies with large and specialised staff normally require more steps and operate with greater detail.

The following examples contain the *most normally used sequences :*

1. *Preproduction drawings :*
   – The first release of drawings must be considered as preliminary or preproduction.
2. *Manufacturing feasibility review :*

All preproduction drawings should be analysed for the following :

— Are dimensioning and datum surfaces compatible with accepted manufacturing practices?
— Are bills of material and casting or forging drawings available?
— Are sufficient stock allowances provided on castings, forgings and stampings to allow for anticipated mismatch or distortion in heat treatment?
— Are sufficient clearances and access allowed for proper assembly of all components?
— Are maximum allowable tolerances, applied to non-functional characteristics?
— Are tolerances and surface finishes on functional characteristic realistic, and is statistical tolerancing used where possible?
— Are adequate clamping and locating surfaces provided for manufacturing?
— Are value analysis suggestions for lower cost applicable?

The information on the above items is collected in the form of comments and is reviewed with responsible design engineer. Acceptable suggestions or trade-offs are agreed upon and incorporated into each applicable drawings, these revised drawings become the *production drawings.*

3. *Make or buy decisions :*
   – Proper decisions (make or buy) are based upon true cost comparisons, in-plant workloads, lead time comparisons, and inplant *versus* vendor capability.
4. *In-plant production considerations :*
   – The two points to consider when preparing to establish process routing are the *anticipated product life cycle* and the *required production quantities.*
5. *Developing the process :*

The method of developing a process remains the same regardless of the variation in product nature, level of production, lead time allowed and the like. The formal *steps* in this procedure are :

(*i*) Create a general statement of the manufacturing operations to be performed.
(*ii*) Establish a provisional process.

(*iii*) Develope alternative processes.
(*iv*) Select a production process.
(*v*) Communicate the selected process to other affected activities.
(*vi*) Perform detailed processing.

6. *Pilot production run* :

- The first production run of a part can be considered a pilot run, as any new process may require some modifications.

7. *Process review and updates* :

Any process change after the first production run must consider the following :

(*i*) Parts or assemblies in process and material on hand.
(*ii*) Cost of change, including effect on tooling, material, and delivery schedule.
(*iii*) Anticipated savings or added cost.

Although cost reduction is a constant philosophy of manufacturing, changes should be made with caution.

19.4. PROCESS FORMAT AND CONTENT

Process format can vary greatly but tends to follow similar patterns in like industries. The document received by the production operator will depend on methods of duplication, distribution and presentation.

Types of formats :

— In some job shops, drawings and handwritten notes serve as format. Still pictures of elaborate operation setups or part assemblies are often utilised either to aid workers or even to be their only process document. At the other end of spectrum are part files kept at each machine consisting of detailed process prints showing specific surfaces, dimensions, finishes and tolerances to be machined for that defined operation step accompanied by computerized procedures detailing every movement made.

— Currently the approach is to use a computer to store and reproduce the required process documentation.

Process content :

For all but very small plants, the following *items are normally mandatory for inclusion:*

- Part identification.
- Process revision information.
- Drawing identification.
- Bill of material information.
- Material identification.
- Operation number.
- Workstation identity.
- Operation description.
- Production time standard.
- Tooling and gauges required.
- Speeds and feeds to use.
- Tool layouts.

- Workpiece layout.
- Process operation drawing.
- Handling equipment.
- Special protection and conditions.

19.5. COMPUTER AIDED PROCESS PLANNING (CAPP) SYSTEMS

— **Process planning** *involves the preparation and documentation of the plans for manufacturing the products. Computer-aided process planning (CAPP) represents the link between design and manufacturing in a CAD/CAM system.*

— The process planning is concerned with determining the sequence of processing and assembly steps that must be accomplished to make the product. The processing sequence is documented on a form called a "*route sheet*". The route sheet typically lists the production operations, machine cells or work-stations where each operation is performed, fixtures and tooling required, and the standard time for each task. During the last decade or so, there has been much interest in automatising the task of process planning by means of CAPP systems.

Following are the *two approaches around which the computer aided process planning systems are designed:*

1. Retrieval CAPP systems.
2. Generative CAPP systems.

1. Retrieval CAPP systems :

- These types of systems (also known as "*variant CAPP systems*") are based on the principles of "*Group technology and parts classification and coding*".
- With these systems, a *standard process plan (route sheet) is stored in computer files and each part code number*. The standard route sheets are based on current part routings in use in the factory, or an ideal plan that is prepared for each family.

Fig. 19.1 shows the *general procedure for using the retrieval computer aided process planning system.*

- A large number of GT based variant process plans are available, such as :
  — NIPLA;
  — MICLASS;
  — CAPP etc.

2. Generative CAPP systems :

These systems *utilise an automatic computerised system consisting of decision logic, formulae, technology algorithms, and geometry based data to uniquely determine the many processing decisions for converting a part from a rough to a finished state.*

In this approach, unlike the variant approach, *no standard manufacturing plans are predefined or stored.* Instead, the computer automatically *generates a unique operation sheet for a part every time the part is ordered and released for manufacturing.*

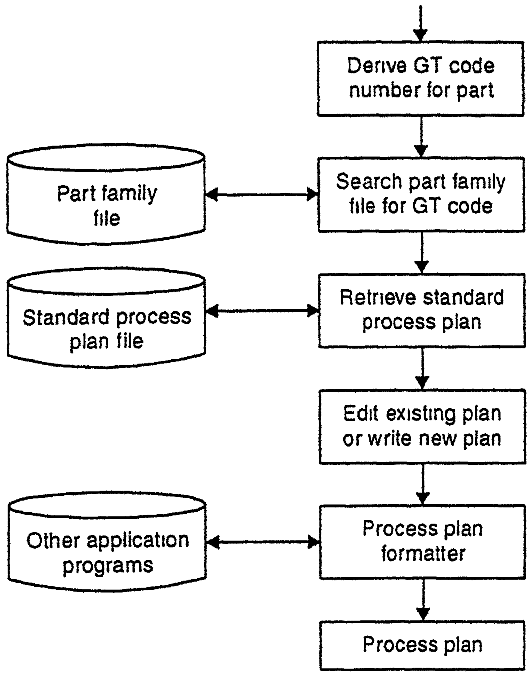


Fig. 19.1. General procedure for using one of the retrieval computer aided process planning systems.

This system consists of the following two major components:

(*i*) ***Geometry based coding system :***

— This component *translates physical features and engineering drawing specifications into computer interpretable data.*

— The coding defines all geometric features, feature sizes and locations, and feature tolerances for all process-related surfaces. The coding scheme not only describes both the rough and finished states, but must be defined in similar terms for the part in each operation. Consequently, the coding scheme for a *generative system requires far greater detail than is required in the variant methods.*

(*ii*) ***Process knowledge :***

— This component is *in the form of decision logic and data in order to compare the part geometry requirements to manufacturing capabilities.* This logic is used to automatically determine the appropriate sequence, selecting the machine for each operation, determining cut planning or any other operation details subject to available tooling and fixturing, and calculating the setup time and cycle times for each operation.

- An additional element of the system is the *software for printing the operation sheet* and/or procedure sheet for instructing the operator according to the methods selected by the computer.
- Although a truly universal general system has yet to be developed, a number of generative systems are available today for specific manufacturing processes or types of parts.

— CAPPGENPLAN packages are normally used.

Advantages of Computer aided process planning (CAPP) :

Following are the *advantage of CAPP :*

1. Increased productivity of process planners.
2. Process rationalisation and standardisation.
3. Incorporation of other application programs.
4. Improved legibility.
5. Reduced lead time for process planning.

QUESTIONS WITH ANSWERS

Q.19.1. What is process planning?

Ans. • **Process planning** *means the preparation of work detail plans.* It involves the detailed planning of the process of production for the product of a specified quality and quality at a minimum cost with available resources.

- This activity is not confined only to the time when a new product is introduced but it is reviewed continuously with a view to achieve increased production of higher quality products at lower manufacturing costs.

Q. 19.2. What are the advantages of "Process planning"?

Ans. Following are the *advantages of process planning :*

1. The net result of process planning is more effective and efficient operation.
2. It facilitates coordination among various agencies.
3. It helps in process improvement.
4. Supervisors are free from detailed task of process planning so that they can concentrate on more productive activities.

Q. 19.3. What information is required to do process planning?

Ans. To carry out process planning, the following information is required :

1. Quantity of work to be done along with product specifications.
2. Quality of work to be completed.
3. Availability of equipments, tools and personnels.
4. Sequence in which operation will be performed on the raw material.
5. Names of equipments on which the operations will be performed.
6. Standard time for each operation.
7. When the operations will be performed?

Q. 19.4. What is the procedure of process planning?

Ans. Following *steps* are involved in the procedure of process planning :

1. ***Selection of process.*** The selection of process depends upon :

— Current production equipment;

— Delivery date;

— Quantity to be produced;

— Quality standards.

2. ***Selection of materials :***

— The materials should be of right quality and chemical composition as per the product specifications.

— The shape and size of materials should restrict the scrap.

3. ***Selection of jigs, fixtures, and other special attachments :***

— These supporting devices are necessary to give higher production rate and to reduce cost of production per piece.

4. ***Selection of cutting tools and inspection gauges :***

— They are necessary to reduce production time and inspect accurately and at a faster rate.

5. ***Making the layout :***

— To make the process layout indicating every operation and the sequence in which each operation is to be carried out.

6. ***Set-up time and standard time :***

— To find set-up time and standard time for each operation.

7. ***Manifest process planning :***

— To manifest planning by documents such as operation and route sheets, which summarise the operations required, the preferred sequence of operations, auxiliary tools required, estimated operation times etc.

Q. 19.5. What are the basic factors which influence process planning?

Ans. The process planning activity begins with the receipt of product specifications and ends with the plans for manufacture of product. As such the first step is a careful review of product-design and specifications, leading to revised product specifications which form the basis for process planning. Thus, the principal initial data required are :

(*i*) Assembly and detail drawings of product.
(*ii*) Specifications for acceptance of the finished products and service function.
(*iii*) Volume and rate of output.
(*iv*) Information regarding plant facilities.

Q. 19.6. Discuss briefly "Process planning activities".

Ans. The task of determining a process plan that defines how to produce a part involves the following distinct *steps*:

(*i*) To analyse part requirements.
(*ii*) To determine operating sequence.
(*iii*) To select machines.
(*iv*) To calculate processing times.
(*v*) To process documentation.
(*vi*) To communicate process knowledge.

Q. 19.7. List the notable objectives for process planning systems.

Ans. In the light of the magnitude and complexity of the data involved, it is essential to have clearly defined objectives both for the development and maintenance of a process planning system. Notable objectives are :

(*i*) Consistency
(*ii*) Accuracy

(*iii*) Ease of application
(*iv*) Completeness
(*v*) Low maintenance efforts.

Q.19.8. Discuss briefly "The evaluation and selection of the best process planning system".

Ans. The evaluation and selection of the best process planning system for a given company encompasses numerous engineering management decisions. The process involves identifying, weighing and comparing various interrelated factors. The *major factors* to consider are :

(*i*) General environment in which process planning is conducted.
(*ii*) The organisational structure of the company.
(*iii*) The technical expertise available to the company.
(*iv*) The needs and objectives of the company regarding the generation of manufacturing information and process plans.

Q.19.9. List the 'aids' and 'techniques' relating to process planning.

Ans. Following is the *list of aids and techniques relating to process planning :*

1. Group technology.
2. Computer aided process planning.
3. Outside processing assistance.
4. Tolerance charts.
5. Line balancing.
6. Simulation.
7. Open-loop control.
8. Closed-loop control.

Q.19.10. What do you understand by "Discrete process control"?

Ans. Discrete process control *deals with systems that discrete information and parts*. Generally, the information is binary; however, this is not a requirement.

Example. An example of discrete process control is *a conveyor and packaging system for crayons*. The machine dispenses the crayons, one of each colour at the same time, into a box. Sensors detect if the crayons were damaged for the box was not filled. A conveyor carries the good boxes to a bundling unit and reject the bad boxes for inspection and packaging.

Q.19.11. What are "Programmable Logic Controllers (PLC)"?

Ans.
- Programmable logic controllers (PLC) are in widespread use for both continuous and discrete process control. Recent developments have provided PLC with increased speed, programming and communication capabilities.
- Modules are now available which provide connection to other factory networks using MAP (Manufacturing Automation Protocol). Most PLCs are designed in moduli fashion :
  — Input and output modules.
  — Communication modules.
  — Special purpose modules.
- PLC programs offer some important advantages over relay circuits. The most important is that relays and other output devices can have an unlimited number of contacts. In contrast, most control relays are limited to a few sets of a contacts and circuits must be designed with this limitation in mind. Generally, this results in few rungs with more

complex logic. PLCs, on the other hand, use an electronic bit to represent each input and output. This single bit can be referenced as many times as required in the program without adversely affecting scans of other rungs because there is not electrical interaction between the elements represented in the rungs.

HIGHLIGHTS

1. *Process analysis* and *operation planning* are required for all manufactured products regardless of their size, material make up, or type of construction.
2. *Process planning* involves the preparation and documentation of the plans for manufacturing the products.
3. Following are the two approaches around which the computer aided process planning systems are designed:
   (*i*) Retrieval CAPP systems, (*ii*) Generative CAPP systems.

OBJECTIVE TYPE QUESTIONS

Fill in the Blanks of Say 'Yes' or 'No':

1. .... analysis and .... planning are required for all the manufactured products regardless of their, size, material make-up, or type of construction.
2. The first release of drawings in process planning must be considered as preliminary or preproduction.
3. The first production run of a part can be considered as a .... run.
4. Process format can vary greatly but tends to follow similar patterns in like industries.
5. .... planning involves the preparation and documentation of the plans for manufacturing the products.
6. In .... CAPP systems a standard process plan is stored in computer files for each part code number.
7. In .... CAPP systems no standard manufacturing plans are predefined or stored.
8. Geometry based coding system translates physical features and engineering drawing specifications into computer interpretable data.

ANSWERS

1. Process, operation 2. Yes 3. pilot 4. Yes 5. Process
6. retrieval 7. Generative 8. Yes.

THEORETICAL QUESTIONS

1. List the data required for effective operation plans.
2. What are the normally used sequences to establish an effective manufacturing process?
3. Discuss briefly 'Process format and content'.
4. What is "Process planning"? Explain.

5. Explain briefly the following two approaches around which the computer aided process planning systems are designed:
   (*i*) Retrieval CAPP systems.
   (*ii*) Generative CAPP systems.
6. What are the advantages of computer aided process planning (CAPP)?

□□□

20

Inspection and Quality Control

20.1. Inspection — Introduction — Aims of inspection — Inspection standards — Types of inspection — Inspection devices, 20.2. Quality control — Definition and scope — Advantages of quality control — Objectives of quality control — Essential or principles of quality control — Statistical quality control — Control charts — Sampling — Advantages of sampling — Acceptance sampling — Single sampling — Double sampling — Standards and specifications — Quality assurance concepts — Functions of quality assurance. Highlights — Objective Type Questions — Theoretical Questions.

20.1. INSPECTION

20.1.1. Introduction

***Inspection** may be defined as the function by which the control of quality is maintained.* It is one of the most important functions of production control. Just as design and production form the main stream of any production line, inspection acts as the control valve which regulates the flow of production along the main stream according to design and specifications In an engineering factory, the design department sets the standards of accuracy which production must comply with and inspection department must enforce. Similarly in a chemical factory the technical department sets the standards for production to comply with and quality control section keeps the check. Not only are the standards of the end products to be maintained but in order to make this possible and easy to detect, inspection exercises quality control at different stages in the process. To do this the inspection must know the critical points at which a stricter quality control is called for. *The responsibility for detection of faulty work and returning it for correction or scrapping lies with the inspection department.*

20.1.2. Aims of Inspection

The main *principles or aims* of inspection are :

1. To determine that the material in process is of uniform quality.
2. To ensure that product is to the desired standard.
3. To initiate means to determine variations during manufacture.
4. To provide means to discover inefficiency during manufacture.

20.1.3. Inspection Standards

Inspection standards are ascertained by design department as per the requirement of goods and are set with an idea to check goods by physical means (such as size, weight, tensile strength and hardness etc.). The inspection standards by which all materials or products are checked are: (*i*) Physical properties, (*ii*) Finish and, (*iii*) Dimensions. Physical properties are variables and depend upon the materials or products concerned. These are determined by various means, the process used depending upon the property to be determined.

20.1.4. Types of Inspection

The inspection may be of the following *types* :

1. Process inspection.
2. Hundred percent inspection.
3. Sampling inspection.
4. Centralised inspection.
5. Floor inspection.
6. Cage inspection.
7. Final inspection.

1. Process inspection. This type of inspection is mainly concerned with the inspecting goods in process. The type of process inspection employed depends largely on the skill of work force, equipment and the tolerances specified. *First piece inspection* is very common type of process inspection. In a machine shop, for example, after a machine has been set up to turn out a part, one or two of the parts are run on the machine and are inspected before the entire lot is produced. The first piece inspection might indicate that adjustments should be made in the machine or it might show that first piece product is of desired specifications and that operator can go a head with the job. Where several successive steps are required to make a product, and the accuracy of each step is dependent upon the accuracy of prior operations, many companies run several pieces through all the steps required in the manufacture of the part. Thus, the acceptability of entire operation is assured prior to processing all the parts through any one step. This type of inspection is usually an extension of first piece inspection and is some times called *pilot-piece* inspection (because a pilot or trial run is made of all the equipment to be used).

Probable causes of defective work affecting the usefulness of the process inspection in whatever form should be given consideration. These are indicated below :

(*i*) Failure of operator to carry out instructions due to (*i*) Unsatisfactory or insufficient training, and (*ii*) Inability of operator to perform the job.

(*ii*) Bad setting.

(*iii*) Wear on tools (which results in the setting becoming incorrect).

(*iv*) Bad setting.

2. Hundred percent inspection. Hundred percent or *cent percent* inspection is quite common when the number of parts to be inspected is relatively small and also where a fault in one major part is likely to affect the operation of a finished product or where there is difficulty in manufacture of the parts and it is liable to errors. Here every part is examined as per the

specifications or standard established and acceptance or rejection of the parts depend on the examination.

3. Sampling inspection. The use of sampling inspection is made when it is not practicable or too costly to inspect each piece. A random sample from a batch is inspected and the batch is accepted if the sample is satisfactory. If the sample is not to the desired specification then either entire batch may be inspected piece by piece or rejected as a whole. Satistical methods are employed to determine the portion of total quantity of batch which will serve as a reliable sample.

4. Centralised inspection. Centralised inspection is carried out in a specially designed inspection area which is separate from production area. The product is brought into this area where supervised inspection procedures are carried out. Highly centralised inspection is an impracticable proposition where larger parts are involved as in the manufacture of steam turbine. These are properly inspected on the floor or at the machine. Central inspection becomes a necessity in the case of small repetitive job tending towards mass production.

Advantages :

The centralised inspection has the following *advantages* :

1. With inspectors in one location, closer supervision over them can be established. With this closer supervision, less skilled inspectors can be employed and in addition, the close supervision makes possible the achievement of a more nearly uniform level of quality.
2. The worker and the inspector are separated, thereby practically eliminating any collusive action concerning whether or not a doubtful product should pass inspection because work is almost always stacked up and waiting for them.
3. Since the inspection work is concentrated in an area, very effective procedures and specialized equipment can be set up.
4. Production control is facilitated.

Disadvantages :

The centralised inspection is associated with the following *disadvantages :*

1. Defective work may be discovered too late to stop a large amount of spoilage.
2. There is more material handling and tie-up of product.
3. There is the need for greater work effort in co-ordinating the flow of materials through production and inspection.

5. Floor inspection. In floor inspection the parts are checked at the point of manufacture. It is usually more effective, and more desirable because time is lost in transporting materials to and from the centralized inspection cribs. This system keeps a constant check on production. In fact, to prevent the manufacture of bad parts many companies provide the machine operators with simple gauges to check the product quality, and the *patrolling inspectors* are only called where questions arise or where the products are not meeting the specifications. In such cases, the inspector usually helps determine and remedy the difficulty in the manufacturing process. Because of the independent nature of their work, floor inspectors are necessarily more highly skilled than those in centralised inspection.

6. Cage inspection. Cage inspection revolves round the idea that inspection should keep in step with production. Here the machines are placed round a fenced portion of works in which inspection staff is accommodated. To carry out the inspection the inspectors are provided with benches and gauges. Work performed in each machine is allowed to pass in convenient batches to the cage suitable for inspector to handle. The parts which come upto the standard specifications or standard desired are retained by the inspector, while the defective parts are sent back to the operator for rectification.

Cage-inspection entails the following *advantages* :

1. Flow of work more even.
2. Adequate saving of labour.
3. Scrap reduction to a minimum.
4. Less movement of work.
5. Easy control of quantities.

7. Final inspection. The final inspection of a product usually takes place close to the point where the work is finished. It ensures that all components comprising the mechanism are in order. Some plants use only a visual inspection where as others give the product rigid tests.

20.1.5. Inspection Devices

Depending on the established level of quality, various techniques and devices are used to determine if a product meets the standards and specifications established by the engineering organisation. An effective inspection procedure for many products consists simply of a visual inspection. This is true in textiles, where colour and flows are determined usually. On more complex products where measurements are critical, various devices are used. Some of the commonly used devices are : (*i*) Inside and outside callipers; (*ii*) Vernier; (*iii*) Straight edge; (*iv*) Try-squares; (*v*) Flexible steel rule; (*vi*) Protector; (*vii*) Trammel steel beam; (*viii*) Inside micrometer and outside micrometer; (*ix*) "Go" and "Not Go" gauges of the following varieties,: Plug, Ring, Gap and Screw; (*x*) Fillet and radius gauge; (*xi*) Dial gauge and (*xii*) Sine bar.

20.2. QUALITY CONTROL

20.2.1. Definition and Scope

Quality control *is an effective system for co-ordinating the quality maintenance and quality improvement efforts of the various groups in an organisation so as to enable production at the most economical levels which allow for further customer satisfaction.* Since this activity is one of the major responsibilities of management quality control must be classified as a "management tool", along with similar tools such as production control and budget control. From the administrative point of view, quality control enters into all phases of industrial production process. It starts with the customer's specification, goes on to engineering, laboratory work, and materials purchasing through factory methods, job planning, manufacturing and mechanical inspection and electrical test to packaging and shipping and then back to the customer, whose needs must be satisfied with a quality product.

Effective human relations is basic to quality control. A major feature of this activity is its

positive effect in building up operator responsibility for and interest in product quality. In the final analysis it is a pair of human hands which performs the important operations affecting product quality. It is of utmost importance to successful quality-control work that these hands be guided in a skilled, conscientious and quality minded fashion.

20.2.2. Advantages of Quality Control

1. Improvement in product quality.
2. Improvement in product design.
3. Reduction in operating costs.
4. Reduction in operating losses.
5. Reduction of production line bottlenecks.
6. Improvement in employee moral.

20.2.3. Objectives of Quality Control

1. To determine size, material, design, appearance, workmanship, finish and other relevant properties.

2. To ensure that products of lower quality may not go into hands of customer.

3. To carefully observe and analyse the deviation from the set standard of quality during manufacture and to investigate the causes leading to such deviation.

4. To apply corrective measures to achieve the real mission of quality control.

20.2.4. Essentials or Principles of Quality Control

1. A competent personnel should shoulder the responsibility for the quality of products.

2. For determining the variations in quality, clear-cut standards should be set up before hand.

3. To ensure that standards of measurement are uniformly applied, an efficient routine should be prepared.

20.2.5. Statistical Quality Control (S.Q.C.)

Statistical quality control *is a special type of inspection which employs mathematical techniques and probability.* In many instances it may be used in place of ordinary inspection procedures. It has been defined *"a method of applying statistical techniques to the collection and analyzing of inspection and other data in order to achieve and maintain maximum economy in manufacturing process"*. Statistical quality control is based on the statistical theories and methods of probability to sample testing. Many of the efforts to ensure proper quality have always been done on sampling basis, that is, a relatively few of the entirely are inspected. However, with statistical quality control the risk involved, in assuming the sample has the same characteristics as a lot, is known and better quality control with minimum inspection cost can be achieved. The risk is not eliminated, but the probability of the reliability of the samples is expressed in numerical items.

Why use statistical quality control ?

One important reason is because it can help prevent defects from being made. In operation, accurate measurements of the parts at the machine are taken, compared to predetermined

standards, and the decision reached whether the operation should continue. When and where to look for sources of trouble are revealed. Costly errors can be located and corrected before large scrap work and rework losses, due to which quality deficiency occurs. Another important reason for using statistical quality control is to supply an audit of quality regarding the producer's products. A universally understood measurement is supplied. In addition, the reasonableness of the quality standards established are checked. Also, savings are enjoyed in that losses due to operations giving non-acceptable quality are minimized.

20.2.6. Control Charts

Controlling the quality of materials, batches, parts and assemblies during the course of their actual manufacture is probably the most popularly recognized quality-control activity. The statistical tool most generally recommended for this work is the *control chart.* Its most prominent pioneer has been Dr. Walter A. Shewhart of the Bell Telephone Laboratories.

A **control chart** *may be defined as "A chronological (hour by hour, day by day) graphical comparison of actual product-quality characteristics with limits reflecting the ability to produce as shown by past experience on the product characteristics.* This comparison is usually made by selecting the measuring samples rather than by examination of each piece produced. The control chart method is a device for carrying out, on a factual basis the shopman's separation of variation into "usual" and "unusual" components. It compares actual production variation of manufactured parts with the control limits that have been set up for those parts. When these limits have been computed and then judged acceptable for use in production, the control chart takes up its major role-aiding the control of quality of materials, batches, parts and assemblies during their actual manufacture.

There are four main control charts : (*i*) $\overline{X}$-chart gives the mean measurement in the sample; (*ii*) R-chart gives the range of measurement in the sample; (*iii*) P-chart gives defectives in the sample, and (*iv*) C-chart gives the number of defects in the sample.

20.2.7. Sampling

Statistical quality control is based on sampling, probability and statistical interference, that is judging an entire lot by the characteristics of sample. Strange as it may seem, sampling has usually been found to be more nearly accurate than 100 percent inspection. The reason for this is that humans get tired of doing the same monotonous work over and over, and errors due to "inspection fatigue" creep in. Another and perhaps more easily understood reason for employing sampling rather than 100 percent inspection is that it is much less expensive where relatively large quantities are involved. This is true because sample sizes do not have to be large.

20.2.8. Advantages of Sampling

1. Time, money and labour are saved.
2. Less damage to the lot during inspection.
3. Number of inspectors required is less.
4. If entire lot on inspection is rejected, it is a pressure for quality improvement.
5. It can be applied to obtain a desired assurance of lot quality even in cases where the tests are destructive in nature.

20.2.9. Acceptance Sampling

A sample is a true representation of the entire lot. The inspection of a sample gives information regarding the goodness or badness of the lot. The sample being a representative of the variables present in the process gives exact idea as to whether the process is doing good job or bad at the time it produces. From this conclusion it is certain that sample gives an idea about the uninspected pieces because the uninspected pieces are the neighbours of the inspected pieces. Now acceptance sampling is valid because uninspected pieces have come and we have labelled as good.

20.2.10. Single Sampling

Acceptance or rejection of lot is based upon the units in one sample drawn from the lot. Select a sample at random from the lot of M say m pieces. Then the sample of m pieces is inspected and if it contains say c or less defectives, the lot is accepted. If it contains more than c defectives the lot is rejected. This procedure is called a *single sampling.*

In short, in single sampling if,

M = Entire lot,

m = Sample,

d = No. of defectives found in the sample,

c = Allowable defectives in the sample,

Then, Accept the lot if $d \leq c$

Reject the lot if $d \geq c$

20.2.11. Double Sampling

Sometimes from the first sample if the number of defective articles exceed the number of allowable articles, then it is desirable to give the lot a second chance. This leads us to *double sampling.* Double sampling is illustrated diagrammatically in the Fig. 20.1.

The advantage of a double sampling plan over a single sampling plan is that a smaller first sample is taken which often provides the evidence necessary for the acceptance or rejection of the lot. Or if additional samples are required, the average size of the total sample is usually smaller. Thus inspection time and effort are saved.

In *multiple* or *sequential* sampling plans the first samples are even smaller than those of the double sampling plan with same types of advantages.

Techniques of quality control :

The principles and techniques by which the variables in a manufacturing process are controlled to achieve the degree of quality desired are as follows :

1. Standards and specifications.
2. Inspection (of materials, parts and products).
3. Statistical technique (including, sampling, analysis and charting).
4. Inspection devices.

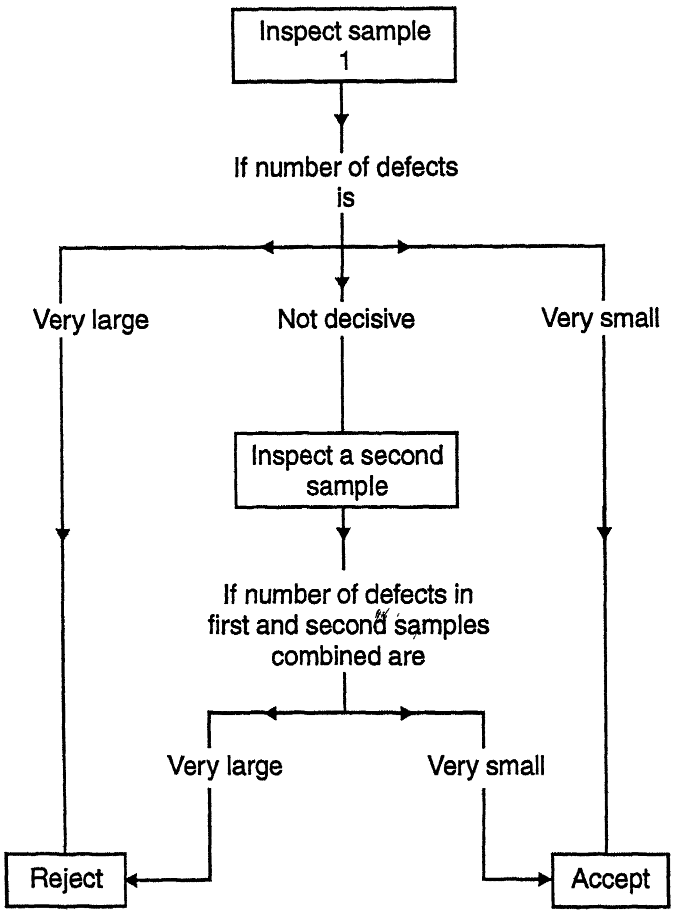


Fig. 20.1.

20.2.12. Standards and Specifications

It is seen that the imperfections which come up in a manufacturing operation are caused by the variables. To reduce the imperfections the variables can be minimised through proper control. Generally the standards of engineering, design process, and materials are determined by those standards which establish the quality of products. Quality standards should be (*i*) measurable, (*ii*) reasonable, (*iii*) available, and (*iv*) understandable. These are generally set by product engineering department in co-operation with the sales, production control, cost and inspection departments. *The standards should in no case be established by inspection department.* The main function of this department is to interpret the standards and to ensure that they are rightly observed.

Inspection. Under quality control programme the two main functions performed by inspections are (*i*) To segregate defective goods and to ensure that only goods of approved quality pass into the hands of customers. (*ii*) To determine flaws in the raw material or in the processing of that material which may crop up trouble at subsequent operations.

The inspection practices usually recognized as the main steps towards contributing to the control of quality through inspection are : (*i*) Control raw materials and purchased parts; (*ii*) Locate inspection strategically; (*iii*) Plan the inspection operations; (*iv*) Inspect for the defects promptly; (*v*) Control inspection output and accuracy; (*vi*) Set up a procedure for handling border line material and (*vii*) Make use of inspection records.

20.2.13. Quality Assurance Concepts

Assurance *means insurance.* **Quality assurance** *means quality insurance. The main purpose of quality assurance is to assure the product is fit for use.* The concept of quality assurance has much in common with the concept of financial assurance. In the quality assurance concept qualified independent auditors examine the quality of the product and issue a certificate that the product is fit to use. *A quality assurance system is an effective method of attaining and maintaining the desired quality standards.* This concept is based on the fact that quality is the responsibility of all functions.

Importance of quality assurance : Importance of quality assurance is felt due to the following reasons :

- *It separates the defective components and parts from other components of required quality.*
- Quality assurance *finds out defects in raw materials and tools,* only good quality materials, proper tools and materials should be used in the production.
- Quality assurance *prevents further work being spoiled* which have been already detected to be defective during inspection.
- Quality assurance of finished product will ensure that the *operation of the product will be safe.*
- Quality assurance detects sources of weakness and trouble in the finished products and thus checks the work of designer.
- Quality assurance *ensures that quality of goods* supplied to the consumers is up to the mark.
- Inspected products sent to the market are of quality and this builds the reputation of the industry and earns goodwill of the consumers, because of quality assurance concept.

20.2.14. Functions of Quality Assurance

Right from the raw materials to the finished product, quality assurances are required to be carried out. They are as under :

- Quality assurance of raw materials.

- Process quality assurance during manufacture.
- Metallurgical and metallographic quality assurance.
- Purchased parts quality assurance.
- Finished goods quality assurance.
- Tool quality assurance.

HIGHLIGHTS

1. *Inspection.* may be defined as the function by which the control of quality is maintained.
2. *Quality control* is an effective system for coordinating the quality maintenance and quality improvement efforts of the various groups in an organisation so as to enable production at the most economical levels which allow for further customer satisfaction.
3. *Statistical Quality Control* is a method of applying statistical techniques to the collection and analyzing of inspection and other data in order to achieve and maintain maximum economy in manufacturing process.
4. A *'control chart'* may be defined as a chronological (hour by hour, day by day) graphical comparison of actual product-quaity characteristics with limits reflecting the ability to produce as shown by past experience on the product characteristics.
5. *Quality assurance* means quality insurance.

OBJECTIVE TYPE QUESTIONS

Fill in the blanks or Say 'Yes' or 'No' :

1. The responsibility for detection of faulty work and returning it for correction or scrapping lies with the .... department.
2. .... may be defined as the function by which the control of quality is maintained.
3. .... inspection is mainly concerned with the inspecting goods in process.
4. The use of .... inspection is made when it is not practicable or too costly to inspect each piece.
5. .... inspection is carried out in a specially designed inspection area which is separate from production area.
6. In floor inspection the parts are checked at the point of manufacture.
7. .... inspection revolves round the idea that inspection should keep in step with production.

8. In cage inspection the flow of work in less even.
9. Effective human relations are basic to quality control.
10. One of the objectives of quality control is to ensure that products of lower quality may not go into hands of customer.
11. Statistical quality control is a special type of inspection which employs mathematical techniques and probability.
12. Statistical quality control is based on sampling probability and statistical interference.
13. A .... is true representation of the entire lot.
14. The standards in no case be established by inspection department.
15. Quality assurance means quality................

ANSWERS

1. inspection	2. Inspection	3. Process
4 sampling	5. Centralised	6. Yes
7. Cage	8. No	9. Yes
10. Yes	11. Yes	12. Yes
13. sample	14. Yes	15. insurance

THEORETICAL QUESTIONS

1. Define the term 'Inspection'.
2. What are the aims of inspection ?
3. What do you understand by 'Inspection Standards' ?
4. Enumerate various types of inspection and explain briefly any two of them.
5. Describe briefly any two of the following types of inspection :
   (*i*) Process inspection.
   (*ii*) Hundred percent inspection.
   (*iii*) Centralised inspection.
   (*iv*) Cage inspection.
6. Explain briefly the term 'Quality Control'.
7. What are the advantages of 'Quality control' ?
8. List the objectives of 'Quality control' ?
9. What are the essentials or principles of 'Quality control' ?
10. What do you mean by 'Statistical Quality Control'.
11. What are control charts ? Explain ?

12. What is sampling ?

13. What are the advantages of sampling ?

14. Explain briefly the following :

(*i*) Single sampling.

(*ii*) Double sampling.

15. Write a short noted on 'Standards and Specifications'.

16. What do you mean by 'Quality Assurance' ?

17. What are the function of 'Quality Assurance' ?

21 Miscellany

21.1. Maintenance management, 21.2. Work study — Definitions — symbols used in work study — steps involved in method study — Recording techniques used in method study-time study — motion study, 21.3. Job analysis, job evaluation and merit rating, 21.4. Wages and incentives, 21.5. Purchasing, 21.6. Stores and store keeping, 21.7. Inventory control, 21.8. Materials handling, 21.9. Financial management and budgeting, 21.10. Network analysis, 21.11. Operation research (OR), 21.12. Manpow planning and control, 21.13. Forecasting, 21.14. Management information systems. Highlights — Objective Type Questions — Theoretical Questions.

21.1. MAINTENANCE MANAGEMENT

Types of Maintenance :

It is very difficult to classify the types of maintenance as it is an integral part of smooth functioning of a plant as a whole. Fig. 21.1 shows types of maintenance. However, the following types of maintenance are important from subject point of view :

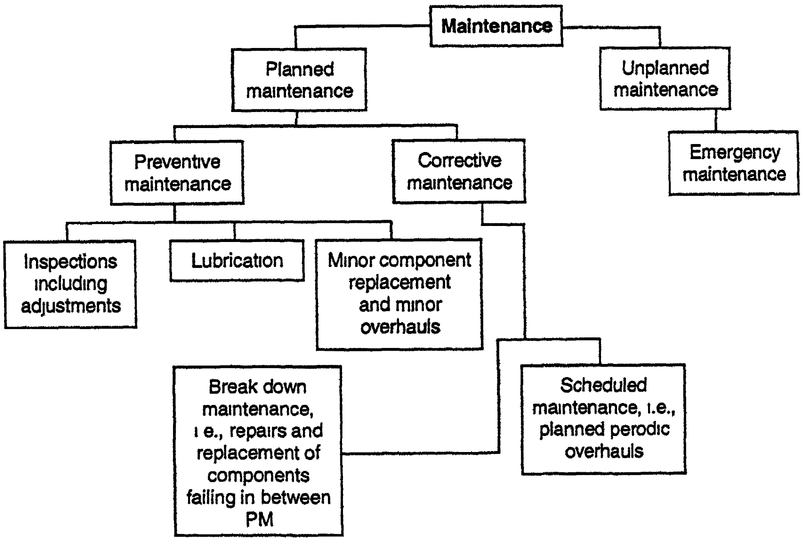


Fig. 21.1. Types of maintenance.

- Preplanned maintenance.

- Breakdown or Corrective maintenance.
- Preventive maintenance.
- Schedule maintenance.

1. Preplanned maintenance :

- The chief feature of organizing proper maintenance is the adoption of orderly and systematic methods. A regular programme should be drawn up in advance for the routine inspections, adjustments and lubrication of machines. When a machine is well cleaned and serviced, both the maintenance man and the operator feel proud of it and try to maintain it still better. *Cleanliness directly helps in tracing cracks and other defects.* Preplanned maintenance is required due to the following *reasons* :
- Increased mechanisation.
- To keep the production failure at minimum rate.
- To reduce the quantity of spare parts.
- To equip machines upto date so as to make maximum use of the available man power and to minimise the disturbance of operation.

2. Breakdown maintenance :

- *Without prior warning or without giving notice sometimes the production machine would have breakdown suddenly.* Priority will be given to emergency breakdown in order to minimise interruption of current productive operation. In all such cases, the causes of the breakdown should be noted and steps are to be taken to see that similar breakdowns do not occur in future.

3. Preventive maintenance :

- *Prevention is better than cure.* It is more efficient than remedial maintenance. The machines and equipments should be inspected periodically to avoid risks and losses which are arising from not making repair before damages had occurred. Preventive inspection should be scheduled according to the needs of given situation. The aims are, to keep machinery in good running order, to maintain continuity of production and to keep off scheduled preventive inspection the department makes timely preventive repairs and adjustments to avoid serious machine failure which would disturb production. Highly skilled employees can help for a good maintenance of equipment in industries.

(*a*) **Objectives of preventive maintenance :**

Following are the *objectives of 'Preventive maintenance' :*

- To get *maximum availability of the plant* by avoiding breakdown and shut-down period.
- To keep the *machine in proper condition* in order to maintain the quality of product.
- To ensure *safety of workers.*
- To maintain the maximum *production efficiency* of the plant.
- To keep the *maintenance economical* and at optimum cost.

(*b*) **Functions of preventive maintenance :**

Following are the *functions of Preventive maintenance :*

- Proper and timely *inspection.*
- Servicing includes *cleaning*, lubrication etc.
- Planning and *scheduling.*
- Records and *analysis.*
- *Training* the *maintenance staff.*
- *Storage* of spare parts.

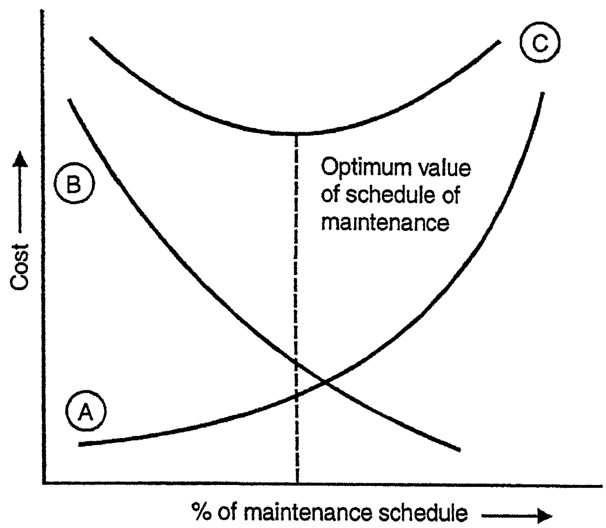
(*c*) **Advantages of preventive maintenance :**

Following are the *advantages of preventive maintenance :*

- *Reduction* in production *down time.*
- *Less standby* equipment.
- *Less overtime* pay for maintenance staff.
- .*Less expenditure* on repairs.
- *Storage of less spare parts.*
- *Greater safety* of employees.
- *Increased* equipment *life.*
- Better product quality and lesser product repairs.

4. Schedule maintenance :

The aim of this maintenance is to avoid breakdown. It includes inspection, lubrication, repair and overhauling of equipment, in a predetermined schedule. It is generally followed for overhauling of machines, cleaning of water and other leaks, white washing of building etc.



A — Breakdown mainenance,
B — Schedule maintenance,
C — Breakdown cost and schedule maintenance cost.
Fig. 21.2. Maintenance strategies.

20.2. WORK STUDY

20.2.1. Definitions

As defined by British Standard Institution, *work study* is a generic term for those techniques particularly *'Method study'* and *'Work measurement'* which are used in the examination of human work in all its contexts and which lead systematically to the investigation of all the factors which affect the efficiency of the situation being reviewed in order to seek improvements.

Standard time. The time taken by a normal worker for a specific task or job under moderate conditions of working.

Standard time = Average time × rating factor + other allowances.

Rating factor. It is also known as *'Levelling factor'*. Time study engineer multiplies actual time with rating factor to get the average time which a normal worker would take. This is

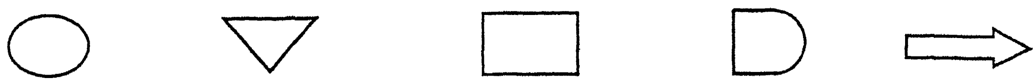
expressed as a percentage of the efficiency of representative operator, which indicates how efficient, a worker is as compared to average fellow workers. Rating factor is generally assumed to be 90 to 120 percent.

Performance rating. Comparison of performance of the operator under observation with normal performance.

$$\text{Performance rating} = \frac{\text{Observed performance}}{\text{Normal performance}} \times 100$$

21.2.2. Symbols used in Work Study

Symbols used in process charting are as follows :



Operation Storage Inspection Delay Transport

21.2.3. Steps Involved in Method Study

1. Select .... the work and area to be studied
2. Define .... the problem
3. Record .... all relevant files
4. Examine .... all relevant facts critically
5. Develop .... a new most economical and effective method
6. Sell .... the new method and find out discripencies
7. Install .... the new method as standard practice
8. Maintain .... the new method by regular checks.

21.2.4. Recording Techniques used in Method Study

(*i*) The Operation Process Chart
(*ii*) The Outline Process Chart
(*iii*) The Flow Process Chart (Material)
(*iv*) The Flow Process Chart (Man)
(*v*) The Multiple Activity Chart
(*vi*) Two Handed Process Chart
(*vii*) The Simultaneous Motion Cycle Chart (SIMO Chart)
(*viii*) The Flow Diagram
(*ix*) The String Diagram
(*x*) The Travel Chart.

21.2.5. Time Study

Definition. *Time study is the analysis of a job for the purpose of determining the time that it should take a qualified person working at a normal pace, to do a job using a definite and prescribed method. This time is called **standard time** for the operation.*

Objectives. The following are the *purposes or objectives* of time study :

1. To serve as basis for determination of a standard time during which an operation may be performed efficiently.
2. A basis for establishing a standard time-data for preparing a fair incentive wage plan.
3. An aid is bringing improvement in methods.

4. Production planning and control purposes.
5. Cost control purposes.
6. To be of great help to the motion study of job.
7. To achieve a uniform flow of work and thus to be helpful in layout of a plant on a scientific basis so that machine capacity may not be unbalanced.
8. To strive for improvement in operating efficiency.

Methods of time study. The three commonly used methods of conducting time study are :

1. Stop watch method.
2. Time recording machine.
3. Motion picture camera.

Time study allowances. The normal time for an operation does not include any allowances; it is simply the time that a qualified operator would need for the performance of the job if he works at a normal pace. It is quite obvious that it cannot be expected that an operator will continue working all day without some interruptions. A little time will be consumed by the worker for his personal needs, for rest and for reasons beyond his control. Such interruptions necessitate allowance which may be classified in the following way :

1. Personal allowance.
2. Fatigue allowance.
3. Delay allowance.

21.2.6. Motion Study

Definition. *Motion study is a management technique linking motion to each other in such a scientific way that bodily and mental fatigue may be eliminated; working conditions, machines and materials best suited to men may be provided resulting in the production of best product.* Frank Gilbreth, the leading exponent of this novel management technique defined motion study as *"the science of eliminating wastefulness resulting from unnecessary, ill directed and inefficient motions"*.

Advantages :

Although motion study is a time consuming and costly process yet it has the following *advantages :*

(*i*) Unnecessary, wasteful and tiresome motions are eliminated.
(*ii*) Minor changes in method and in equipment may be devised.
(*iii*) It makes possible the effective distribution of work, arrangement of work place and tools.
(*iv*) It exerts a solutary influence upon the general morale of an organisation when the savings made are shared with the employees.
(*v*) Various methods of performing operations may be changed and newer and more effective ones found.
(*vi*) It enhances productivity and results in the reduced cost of production.
(*vii*) Motion study promotes operation planning in a scientific way and establishes the time standard accordingly.
(*viii*) Data are always secured from which a series of job specifications may be developed.

Operation charts. The operation chart or the left hand and right hand chart is a very simple and effective aid for analyzing an operation. Here no timing device is required and on most kinds of work the analyst is able to construct such a chart from observations of the operator at work. The main objective of such a chart is to assist in finding a better way of performing the task, but this chart also has definite value in training operators.

While preparing operation charts two symbols are commonly used. The small circle represents transportation, such as moving the hand to hold an article and the large circle indicates such actions as holding, positioning, using or releasing the article. In signing a letter with a fountain pen the left hand holds the paper while the right hand performs the various movement as indicated in the Fig. 21.3.

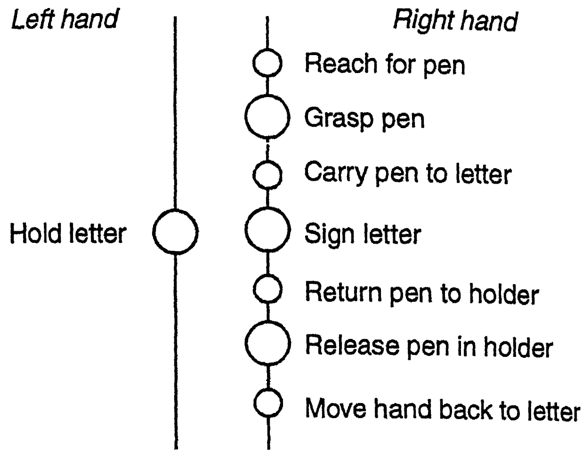


Fig. 21.3. Operation chart showing the movements of the two hands in signing a letter.

An operation chart involves the following *steps* in its preparation :

(*i*) Draw a sketch of work place, indicating the contents of the bins and location of tools and materials.

(*ii*) Watch the operator and movement of his hands, observing one hand at a time.

(*iii*) Record the motions or elements for the left hand on the left hand side of a sheet of paper, and in the similar way record the motions for the right hand on the right hand side of the sheet. Usually a necessity is felt to redraw the chart as it is rarely possible to obtain the motion of the two hands in proper relationship on the first draft.

Flow process chart. It *is a graphic representation of various activities occurring on the plant floor.* It is an elaboration of an operation process chart and assimilates transportation, storage and delay. A flow process chart traces the parallel flow of two or more components through their respective fabricating operations and their subassembly and final assembly.

The flow process chart accumulates and classifies the complete information necessary for the analysis and improvement of plant operations as a whole or of one phase. An improved flow process chart provides an important basis for revising an existing plant layout. This chart is also used to check and verify the efficiency of a proposed floor plan for a new plant.

To prepare a flow process chart (Refer Fig. 21.4) the engineer must visit the plant to study and record the plant activities step-by-step. When the chart is completed the engineer will have an intimate knowledge of the present process and layout. These charts can be prepared with little difficulty for a plant that is manufacturing standardized products. In case of job lot plants, however, it is usually felt necessary to prepare a number of generalised process charts, which will account for large bulk of output. It necessitates the accumulation of data found on the route cards of past orders. The production orders are studied and classified into categories that require

the same or similar production processes. When such data are ready, the engineer will follow step-by-step and record on the chart all the activities necessary in the production of each important category of customer's orders.

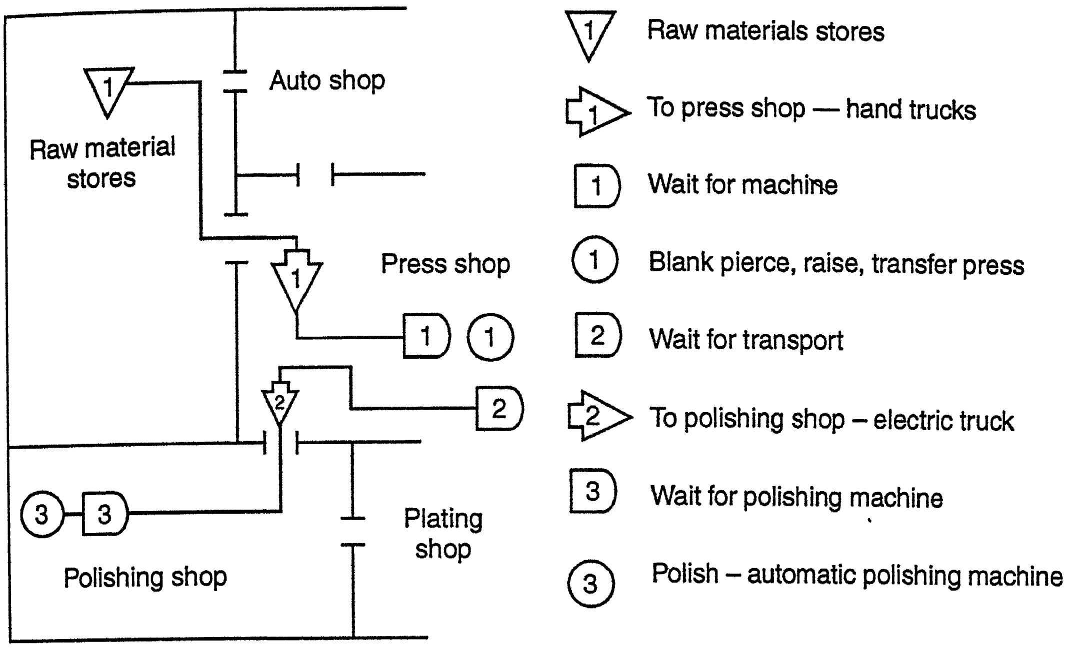


Fig. 21.4. Flow process chart.

Flow diagram : *A flow diagram is an aid to the visualisation of the movement of the materials on an existing floor layout.* This type of diagram is prepared on the floor-plan drawing or on an onion sheet superimposed on the floor plan drawing or blue prints. Use of colour lines is made to trace the flow of work through the machine stations and fabrication and assembly operations required for the output of different products. In case of job-lot plants, the flow of typical jobs or general flow of groups of jobs that require more or less similar production operations can be represented by a number of colour lines. A flow diagram analysis indicates where long lines of handling, back tracking, criss crossing, bottlenecks and confusion exist in the present arrangement and where production operations and service activities are located. In short, the flow diagram checks the effectiveness of overall arrangement of plant activities for materials handling and suggests where revisions can be made. Such an analysis enables the engineer to determine which machine stations, assembly areas, store rooms, office space, locker rooms etc. should be relocated to attain a greater economy in handling Fig. 21.4 shows a flow diagram and a flow process chart.

Multiactivity charts. A multiactivity chart is used whenever it is necessary to consider the activities of a subject in relation to one or more others on the same document. By means of separate bars placed against a common time scale to represent the activities of individual worker or machine during a process, this chart indicates clearly periods of ineffective time with the

process. The construction of this chart also helps in a way that the most important subject from the aspects of costs receives the major emphasis. Furthermore it is particularly useful for enabling maintenance and similar work to be organized in order that the time expensive equipment out of commission is reduced to a minimum. It is also a useful means, when organising team work deciding the number of machine workers and for such like purposes. It assists in recording complex processes in a simple way for study at leisure.

Chart's construction. The activities in respect of workers and machines are usually recorded by shading the respective bars. The timings which can be built up from previous measurements or by direct timing, need only be adequately accurate to ensure that the chart will be as effective as possible. The timings determined by clock or wrist watch are sometimes sufficient; however, frequently it will be necessary to ascertain times by one of the techniques of work measurement. The activities are then plotted in sequence against time scale within their own partucular bar on the chart. Fig. 21.5 shows a multiple activity chart for the job writing a letter using a short hand typist.

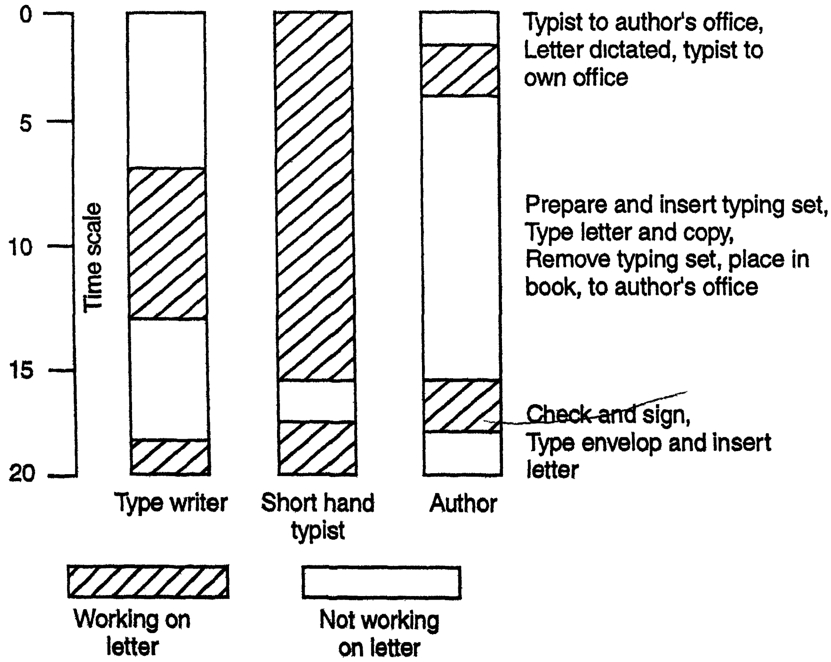


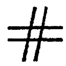
Fig. 21.5.

Man machine charts. A man-machine chart is a record of the simultaneous activities of men and machines. It is similar to the multi-activity chart except that the work done by a machine is also listed in a sequence column. Its purpose is to facilitate the study of work performed so as to arrive at a better distribution of work between the man and the machine. By analysing these charts we find, for example that one man can easily run three machines, or a man machine study may show that we need two men to operate one machine efficiently. Man machine charts can be used to study any combination of men and machines — two men and six

machines one man and two machines and so on to develop a better method of performing the work, there by gaining for management a greater control of labour costs.

Micromotion study. Micromotion study is the study of very small elements of motions (called *therbligs*) and their analysis for the work cycle frequently with the help of a special camera. Frank B. Gilbreth was the leading protagnist of this study. The study makes use of a microchronometer ('wink' clock) in the back grounds which records the therbligs, *i.e., ultra small elements* and measures the time by taking pictures at a constant speed. *Its application is economical only in those concerns where identical tasks are being performed by a number of highly skilled operators.*

Therbligs. Gilbreth introduced certain symbols called '*therbligs*' to indicate human movement such as follows :

	search		find		select
	grasp		hold		transport (loaded)
	position		assemble		use
	disassemble		inspect		pre-position
	release load		transport empty		rest
	unavoidable delay		avoidable delay		plan

21.3. JOB ANALYSIS, JOB EVALUATION AND MERIT RATING

Job analysis. It is a detailed and systematic study of job to find out the nature and qualifications of the people required for efficient performance of job. Job analysis reveals the tasks which constitute the job, the skills, and knowledge required for the successful performance of various tasks.

Job description. It is a formal and organised statement of the contents of a job.

Job specification. It states the minimum human qualities required to perform a job efficiently. It lays the requirements which the person selected for the job should satisfy.

Job standardisation. It involves the establishment of uniform mechanical facilities and methods and combines the specifications of human standards, so that efficiency can be maintained.

Methods of job evaluation. The important methods of job evaluation can be *classified* as under :

A. *Non-qualitative methods :*

(*i*) Ranking or Grading methods (*ii*) Classification method

B. *Quantitative methods :*

(*i*) Factor comparison method (*ii*) The point rating method.

Merit rating or performance. It is defined as, *"the process of evaluating the employee performance on the job in terms of requirements of the job".*

21.4. WAGES AND INCENTIVES

Nominal wages. The amount of money paid to a worker for his efforts is known as *nominal or monetary wages.*

Real wages. It is money value of all the facilities like free accommodation, free medical aid etc.

Living wages. The money that can meet some requirements of workers like food, cloth, education for children, medical care insurance etc. are known as *living wages.*

Fair wages. The wages that are sufficient to meet the basic necessities of life, are known as *fair wages.*

Classification of wage payment plans. A wages payment plan is one which satisfies the workers and at the same time brings profits to management.

Wage payment plans can be *classified* under two groups :

1. Non-incentive plans like Time or Day rate system, and
2. Incentive wage plans like piece rate and other schemes.

Wage plans not based on time study. The following are the wage payment plans or systems not based on time study.

1. Day rate or time study.
2. Piece rate system.
3. Combinations of time rate and piece work systems.
4. Halsey premium wage plan.
5. Rowan plan.

1. Day rate or time rate system. This system of payment involves the time as the basis of payment. It is the oldest of wage payment systems. Under this system the employees are paid at the rate so much per day or per hour of work done irrespective of the quantity of the work performed. *Presently this system of remuneration is commonly used as the basis of calculating the amount payable to indirect workers such as formen, supervisors, time-keepers, cleaners, engine men, gate men etc. as the nature of their nature of work is such that 'time' above can be considered as the basis on which to remunerate them.* Furthermore 'Time Rates' are essential in certain industries where the work can not be standardised or classified into suitable grades for piece rating. This system can be made more effective by careful classification of workers into certain grades according to their skill, capacity and willingness to work, and by fixing different scales of day wage in direct relation to their usefulness.

Advantages :

1. It is simple and easy to understand.
2. It proves quite satisfactory if the rates indicate the value of time spent on work.
3. The quality of work is improved as the workers are in no hurry to enhance the output.
4. It requires less administrative attention.
5. Trade unions favour this system as it involves simpler calculations.
6. It does not involve any physical overpressure because here it is not essential for the workers to overstrain themselves for boosting up the production.
7. It provides the worker some security against sudden reductions in his income as a result of unavoidable accident or sickness or fatigue from outside activities.

Disadvantages :

1. It provides no incentive to an efficient person.

2. It does not provide any measure to reward a good worker and punish the loafer.

3. "The day work method of payment" says Franklin, "permits many a man to work at a task for which he has neither taste nor ability, when he might make his mark in some other ....".

4. The herding together of men into classes regardless of personal character and performance leads to employer—employee trouble.

5. As it provides no encouragement to work hard; to keep the workers working foremen and supervisors have to keep a strict watch on them.

2. Piece rate system. Under this plan workmen working in given conditions with given machinery are paid exactly in proportion to their physical output .... a workman is paid, from the stand point of the moment in direct proportion to his output, the actual amount of the pay per unit of service being approximately equal to the (marginal) value of his services in assesting the machinery to make his output. In this system employee makes all the gain or loss of his time. If he puts in more labour he will get more remuneration and if he waste his time his remuneration may fall below time wages. *This system is liked by the employers as they get more profit with the increase in production.*

Advantages :

(*i*) The efficient workers are benefitted whilst the inefficient are punished in terms of decreased remuneration.

(*ii*) The workers are contented as wage payment is in due proportion to their efforts.

(*iii*) It enables easy computation of cost.

(*iv*) Estimating of jobs is facilitated as the piece work rates are known.

(*v*) The quality is maintained as the worker is paid only when his work has passed inspection.

(*vi*) The total costs are reduced, for while direct labour costs remain constant at all speed of performance, the increase in the amount of work done per hour decreases the hourly charge on account of plant or management.

(*vii*) This system not only increases the output and wages but brings improvement in methods of production as the workers demand materials free from defects and machinery in proper working order.

Disadvantages :

(*i*) When some work earn too much money, the employers tend to exercise a 'cut' in the rate which creates grounds for discontentment of the workers and consequently friction between employers and employees develops.

(*ii*) Too much hard work done by the workers to earn more and more tells upon their health.

(*iii*) While payment based on speed provides an incentive for greater volume, it discourages quality and judgement.

(*iv*) Straight piece work does not guarantee day wages, so that a worker may at times earn

below the subsistence level. Such fluctuations in earnings burden the workers with constant worry and annoyance.

(*v*) The whole of the benefit of extra wages earned goes to the workmen.

3. Combination of time rate and piece rate system. Under this system, a workman receives a fixed minimum weekly wage irrespective of the work done by him, provided he has worked for the full week. In case he works for lessers number of hours, his weekly wages would abate proportionately. For example, if the minimum weekly (assuming the week to consist of 48 hours) wage is fixed Rs. 24/-; if the workman works for 40 hours only, he will get Rs. 20/-. So far the system of payment is based on time rate. Let us further assume that each piece of work allotted to the worker is priced at Rs. 3/-. The worker will have to prepare 8 pieces to earn Rs. 24/-. If he completes 9 pieces within 48 hours he will earn Rs. 27/-. In case he is able to complete only 6 pieces, he will still be paid his minimum weekly wage of Rs. 24/- but as he earned Rs. 18/- on the piece rate basis he will have to make good the excess Rs. 6/- paid to him out of his subsequent wages.

The main disadvantage to the employer is that benefit of extra wages goes to the workers. This has resulted in the development of several Premium and Bonus methods of payment which provide for a portion of savings in wages to pass to the employer, and thus serves to unify the apparently opposite interests of employer and the employed.

Incentives. Incentives may be defined as *type of motivation that influences or arouses interest in the people to work.* When a number of persons are working on similar types of jobs; it is but natural that productivity capacity of individual will vary. The worker whose productivity is higher than the normal, naturally expects some kind of incentive from the management. It is obligatory on the part of the management to give some reward to the efficient workers.

The incentives may be broadly classified as :

1. Positive incentives.
2. Negative incentives.

Positive incentives are further *classified* as :

(*i*) Financial.

(*ii*) Non-financial.

(*i*) *Financial incentives.* These incentives may be (*a*) short range and (*b*) long range.

Short range incentives include (*i*) Time rate, (*ii*) Piece rate, (*iii*) Other incentive plans, such as Hasley plan, Roman plan, Gantt plan, Taylor plan etc.

Long range incentives includes profit sharing and partnership.

(*ii*) *Non-financial incentives :* The different non-financial incentives are :

1. Good working conditions.
2. Less hours of work.
3. Security of job.
4. Pride of belonging to an organisation.
5. Good designation.
6. Fairness in dealings.
7. Proper welfare and security etc.

8. Counselling facilities.
9. Recreational facilities.
10. Full opportunities for training and advancement.

2. *Negative incentives :*

1. Fear of punishment.
2. Fear of dismissal.
3. Fear of demotions.

4. Halsey Premium wage plan. This was one of the first incentive plan that deviated from some form of straight piece work. It was devised by F.A. Halsey and was one of the first, if not the first, to use a guaranteed base and express standards in terms of time rather than money. It sets a standard time, usually by determining the average previous time during which the job can be completed, and offers the workman an agreed percentages of wages of any portion of this time that he may save, in addition to his hourly or daily rate for the time consumed on the job, it will not be reduced, despite the fact the conditions may not have been standardized or jobs studied. Under this system *day rate is guaranteed.* The system is liberal with the time allowance rather than with the premium percentage. *Here* $33\frac{1}{3}$ *to 50 percent of the time saved by the worker on the standard time for a particular job is credited to the worker.* So the worker's earnings will amount to wages on actual hours worked plus $\frac{1}{3}$ to $\frac{1}{2}$ of time saved on the basis of his time rate.

Advantages :

1. It is easy to introduce as no preliminary study is necessary except the circulation of previous average times.
2. By distributing the profit of saved time between management and men, it makes for the permanence of the bonus rate, as both parties benefit by it.
3. The psychology of the plan is adroit : an employee is satisfied with what he gains although part of the saved time by is shared by the employer.

The main *disadvantage* of the plan is that it possesses the weakness of the straight piece rate of taking an unscientifically determined standard time for its job. It depends upon the past performances instead of making new standards. From the point of view of administration, the policy is one of drift as in this plan the worker is left alone to decide whether or not produce more after the standard is reached.

5. Rowan plan. It is the modified form of Halsey system. This system like that of Halsey leaves previous conditions of operation and management undisturbed. Standard times are based on experience. *A time wage is guaranteed to those who fail to reach the standard.* Like the Halsey system the chief aim of Rowan plan is to ensure the performance of the premium rate, by limiting the earnings a workman can make by unusual saving in time. The plan differs from the Halsey plan in the method of bonus determination. Briefly stated, the rule of remuneration under this plan is that the *wage of time taken shall be increased by the same percentage as that by which the time set for the job has been reduced.*

Rowan system is more liberal than the Halsey system upto $\frac{2}{3}$ *time economy, but after that it is less liberal. Moreover, the maximum a worker can earn under Rowan plan is double the guaranteed wage, which is humanly impossible. Like Halsey plan, the Rowan plan can also be used for transitional purposes. The Rowan plan, however is fairly difficult for employees to understand.*

Wage plan based on time study. The following wage plans are based on carefully established times :

1. Taylor's different piece rates.
2. Gantt task and bonus wage plan.
3. Emerson plan.
4. Bedaux or point system.
5. 100 percent bonus plan.

1. Taylor's differential piece rates. In this system of payment, the task is set at a very high level. Here two piece work rates are used, the higher rate being applicable to a workman who completes the task in the standard time or less, and, the lower one for the worker who falls short of such standard. In this method of wage payment *day wage is not guaranteed.* The standard of efficiency is arrived at as a result of close analytical time study of each job. In order to facilitate highest efficiency, plant conditions are highly standardised and every possible care is taken by the management to eliminate all waste of time such as waiting for tools, material etc.

This system is suited to those establishments in which indirect expenditure is very heavy in comparison with the cost of labour.

Advantages :

1. Sincere and good workers are always able to earn wages at a higher rate than the scheduled time rate.

2. If the task level is reached by the worker, his earnings will rise sharply. This acts as a great incentive for him to do his best.

3. Management is also benefitted whether a worker turns out one, two or three pieces within a stated time, the "fixed overhead for that period will remain unaltered". The overhead charges per piece will be reduced, and the production of the articles will become more economical.

Disadvantages :

1. The penalty inflicted on the slow workers is rather harsh.

2. Since the standard is set at very high level, the workers have to exert themselves tremendously; consequently they lose their health with the passage of time.

2. Gantt task and bonus wage plan. Under this plan, not only does the workman receive a reward which is large enough to make him want to make standard, but also he is guaranteed his hourly rate if he fails to reach the goal. If he completes the work, he is paid at his regular hourly rate for the time allowed for the task, plus a percentage of that time. The piece work rate in this case is usually lower than the higher rate offered under the Taylor system, as the slow workers are not penalised but receive their usual time rate. The time and bonus for each job are fixed, the bonus being a fixed percentage on the time taken.

Advantages :

1. By guaranteeing a minimum wage rate, the system does not penalise those workers who fail to achieve the standard of bonus.

2. As foreman also get the bonus, they put in hard labour to bring the work of their workers to the bonus standard.

Disadvantages :

1. As a time rate is guaranteed to every worker, many workers do not exert themselves to reach the set standard and usually feel satisfied with the guaranteed wages. This increases the direct labour and overhead charges per piece.

2. As the piece work rate is usually lower than the highest rate offered by Taylor system, therefore efficient workers do not like this system in comparison to Taylor System.

3. Emerson plan. This plan of wage payment sets also a high task level similar to those of Taylor and Gantt. The system guarantees a daily wage rate and fixes a certain standard output which represents 100 per cent efficiency. The workers which show upto $66\frac{2}{3}$ per cent of the efficiency standard are paid only wage rate and no bonus. If the efficiency exceeds this percentage bonus is paid on a graded scale in a fixed ratio to the increased output. Thus when the efficiency is 90 percent, the bonus payable is 10 percent; when 100 percent, the bonus is 20 percent, and further, with every 1 percent rise in efficiency the bonus increases by 1 percent.

Its chief disadvantage is that majority of workers excepting a few highly ambitious ones, feel satisfied with the guaranteed day wage plus low bonus and thus do not show keen interest in increasing their efficiency.

4. "Bedeaux or Point system". Bedaux system of wage payment makes use of a special unit of measurement of human effort called a 'point' or 'B' which represents a certain amount of useful work plus time allowances for unavoidable delay and rest, the total of which can be accomplished by an average worker working at a normal speed in one minute. The ratio of actual work to rest or delay in a 'point' will of course vary in different types of work, but in all cases, the standard task would be measured by "60 point hour", *i.e.,* the achievement of 60 units or *B's* in one hour. The number of *B's* allowed for a given piece work is the point standard for a job. The value of the number *B's* produced by an individual worker in an hour excees of 60 *B's* per hour is shared by direct and indirect labour. The worker usually gets 75 percent and the remaining goes as bonus to foremen, supervisors and indirect labour.

This plan has the limitations in the cost of time studies, amount of inspection needed and the extensive use of clerical work.

5. 100 percent bonus plan. The main feature of the plan is that the worker gets 100 percent of the bonus earned. In this way it compares with 'Straight Piece' work wage payment system, and differs from Holsey plan in which the worker gets a portion of the time saved. It deviates from straight piece rate in respects that the standards are expressed in time per unit of production rather in money. The time saved is multiplied by the full value of the hourly rate, with result that a rapid worker is paid a guaranteed hourly wage, plus the additional amount that a slower, standard worker would have eventually received upon completing the same quantity

of work. This plan, in effect, is a straight piece-rate together with a guaranteed rate per hour, which is paid regardless of speed. After the standard speed has been attained, the total pay is exactly the same as if a straight piece rate were used.

Special forms of wage payments :

1. Group bonus plans.
2. Profit-sharing plans.

21.5. PURCHASING

- **Purchasing** may be defined as, *"Business activity directed to secure the materials, supplies and equipment required in the operation of an organisation."*
- The following techniques are used for carrying out purchasing :
  (*i*) Single tender basis (*ii*) Spot quotations
  (*iii*) Limited tender basis (*iv*) Open tender basis.
- The following procedure is adopted for processing of tenders and issue of supply orders :
  (*i*) After opening the tenders, comparative statement is prepared to compare the relative price and data.
  (*ii*) Normally, lowest rates are accepted if it conforms strictly to specifications.
  (*iii*) When rates other than lowest are to be accepted, a note mentioning reasons for accepting next higher should be recorded in the comparative statement.
  (*iv*) Finally, supply order is placed and follow up action taken for timely supply of materials.
- In **Centralised purchasing**, the entire purchasing is carried under the responsibility of a single person.
- Generally *small units apply centralised purchasing* techniques *while large units having multiple activities use decentralised purchasing.*

21.6. STORES AND STORE-KEEPING

- Store-keeping is a *function of receiving, storing and issuing of materials.*
- *Centralised stores* are used in small industries.
- Decentralised stores are used in large industries.
- The principle of *'first in first out'* should be followed by a store-keeper.
- A number of records are maintained by a store-keeper for keeping record of items. These are :
  (*i*) Bin card (*ii*) Inward registers
  (*iii*) Outward register (*iv*) Stock registers
  (*v*) Railway receipt register (*vi*) Issue register
  (*vii*) Surplus stock register.
- As soon as material is received in an industry, it must be subjected to proper verification and inspection.
- Store verification is necessary :
  (*i*) To check accuracy of stores. (*ii*) To verify physical count in case of doubt.
  (*iii*) To be ready for internal audit. (*iv*) To prevent theft/pilferage of costly items.

21.7. INVENTORY CONTROL

Inventory :

- *Inventory* includes not only materials and supplies but also machinery spares or other items which are subject to yearly depreciation charges. These latter must be stored; they must also be separated and carefully accounted for. Inventory costs money. This cost has been rightly called cost of possession. It involves several items all important. It is to control the cost of possession of every business that employs an inventory control system. Some firms exercise too much control, and cost of control, eats them up. Others do not employ enough control, inventory costs that is cost of possession are not excessive. In others, the system inventory control is economical and adequate at the same time.
- *Inventory control* refers to the physical verification of the stock in the stores, intended to determine the state of affairs of the store organisation. It brings out to light if goods are being issued and maintained properly.

Objectives of inventory Control. An inventory control routine logically established and applied, employing competent personnel and ultilizing where applicable the forms and techniques should accomplish the following objectives :

1. Maintain a supply of materials adequate to meet the production requirement in both quantity and quality.
2. Reduce the investment in these materials to a minimum.
3. Assure that materials received are in accordance with the specifications set forth on the purchase order.
4. Safeguard all the materials by proper storage against theft breakage and deterioration.
5. Supply the producing department with the materials required at the times and places designated and prevent the misuse and diversion of the materials to improper destinations.
6. Maintain inventory records showing receipt, disposition and use of materials issued and quantities and kind of materials in stock.

Inventory control must be fluid, must adjust rapidly to external forces. Some of these external forces are not merely business variables, they have social implications—war, threat of war, storm, persistent strike in supplier industry, crop failure etc.

Pre-requisities of an inventory control system :

1. An adequate, enclosed, well arranged store room with (*i*) definite location of material (*ii*) definite identification of material.
2. Provision for eliminating slow moving and obsolete items.
3. Centralisation of authority and responsibility with an adequate staff to man the function, particularly a responsible, preferably bonded store-keeper.
4. A system for count and inspection of material upon receipt.
5. Absolute control of issuance of materials.
6. Periodic physical inventory.
7. Checks to ascertain enforcements of routine.

Organisation. Inventory control, in continuous manufacturing, is generally part of Production control because of the necessity for maintaining a flow of materials needed for the efficient and continuous operation of the production line. In intermittent manufacturing, as the need for a steady flow of materials is not so urgent, inventory control may be the responsibility of the plant manager, production superintendent, purchasing agent or a similar person, depending on the plant size and organisation. In smaller plants, purchasing agent is usually responsible for purchasing as well as maintaining an adequate supply of material

Inventory quantity standards. There are four quantity standards :

1. The reorder point.
2. The standard order.
3. The maximum.
4. The minimum.

Each of these quantity standards are illustrated by Fig. 21.6.

1. *The reorder point.* It indicates when to order and prevents the exhaustion of material. Thus if a recorder point of say 130 has been set, a new order will be issued when the quantity on hand reaches 130, or when the quantity available reaches 130 if the apportionment feature is used.

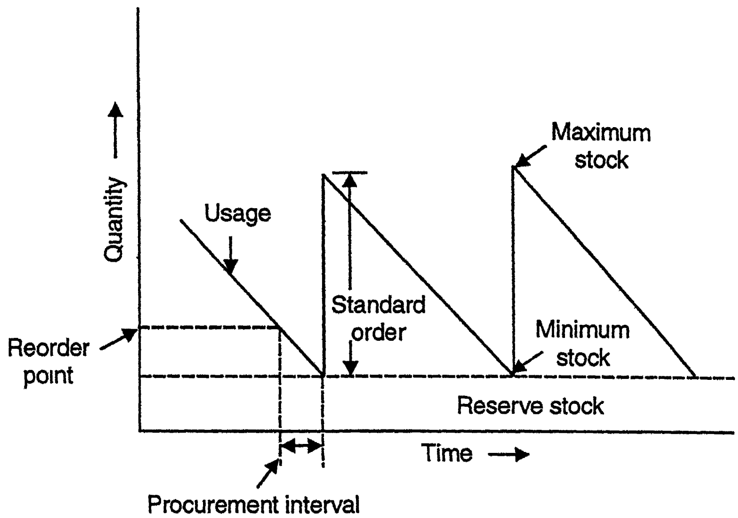


Fig. 21.6. The four quantity standards.

2. *The standard order.* It shows how much to order. It indicates the most economical purchase lot size. A purchase requisition is issued for the standard amount when the reorder point is reached.

3. *The maximum.* It represents the upper limit of the inventory. Ordinarily, no quantity of materials will be purchased that will cause the stock condition to rise above the maximum quantity. The purpose of establishing a maximum inventory is to prevent acquiring too much material and thereby needlessely tying up storage space and capital. A maximum inventory also assists in determining the storage space to be allocated for materials.

4. *The minimum.* It indicates the lower limit of the inventory. The minimum acts as a margin of safety.

Economic Ordering Quantity. The most economic ordering quantity is calculated by procurement and inventory (storage) carrying costs.

Purchasing cost consist of expenses for calling quotations, tenders, placing orders, inspection and other incidental charges. Inventory cost includes taxes, insurances, storage, handling and spoilage of the material. The theoretical economic ordering quantity is decided as follows :

Let, A = Annual usage in units,
S = Set up cost per order,
I = Annual inventory carrying cost per unit, and
Q = Economic ordering quantity.

Procurement cost per year

= Number of orders placed per year × buying cost per order

$$= \frac{\text{Annual usage in Units}}{\text{Economic Ordering Quantity}} \times \text{Buying cost per order}$$

$$= \frac{A}{Q} \times S = \frac{AS}{Q}$$

Inventory carrying cost per year

= Average quantity of stock in inventory per year × annual inventory carrying cost per unit

$$= \frac{Q}{2} \times I = \frac{IQ}{2}$$

$$\text{Total cost per year} = \frac{AS}{Q} + \frac{IQ}{2}$$

This will be minimum when the procurement cost equals the inventorying carry cost

i.e., $\dfrac{AS}{Q} = \dfrac{IQ}{2}$

$$\therefore \quad IQ^2 = \frac{2AS}{I} \qquad \therefore \quad Q = \sqrt{\frac{2AS}{I}}$$

$$\textit{Economic Ordering Quantity} = \sqrt{\frac{2AS}{I}}.$$

Example 21.1. *The manager of a factory is purchasing forgings of outer-ring Rs 10000 annually. Records reveal that cost of an order is Rs. 15; cost of inventory carrying is 9% of the average inventory value and unit price is Rs. 65. Determine :*

(*i*) *Economic order quantity* (Q_{opt})

(*ii*) *Optimum number of orders per year.*

(*iii*) *Optimal cost of ordering and inventory carrying cost.*

Solution. Set up cost (S) = Rs. 15 per order

Inventory carrying cost (I) = 0.09 × 65

I = 5.85 per unit per year

Annual demand A = Rs. 10000 per year

$$(i)\ \text{EOQ} = Q_{opt} = \sqrt{\frac{2AS}{I}}$$

$$= \sqrt{\frac{2 \times 10000 \times 15}{5.85}} = \mathbf{226.45\ (Ans.)}$$

(*ii*) Optimum number of orders per year

$$= \frac{\text{Demand}}{Q_{opt}} = \frac{10000}{226.45} = 44.15 = \mathbf{45\ (Ans.)}$$

(*iii*) Optimal cost of ordering and carrying

$$= \sqrt{2\ ASI} = \sqrt{2 \times 10000 \times 15 \times 5.85} = \mathbf{Rs.\ 1324.76\ (Ans.)}$$

ABC Analysis (Value Classification) :

- It is meant for relative inventory control in which maximum attention is given to those items which consumes more money and a moderate attention is given to those items which are of medium value, while the attention for low value items is reduced to routine procedure only.
- The first category, small numbers of high consumption cost items are called **"A-items"**. Second category of medium consumption value items are called **B-items.** Third category of large number of items with small annual consumption value are classed as **C-items.**

The general principles of ABC Analysis can be applied to almost any activity. For example, a business may divide sales into ABC categories. Its best lines of sales and the most lucrative ones would be A items whereas miscellaneous items which do not bring in much profit would be C items, the rest being categorized as B items. Similarly, production programmes could be so divided depending on the importance of various jobs to be performed. The same applies to office routine. All successful organizations, in fact, adopt an ABC analysis system, perhaps, without actually knowing that they are doing so. *Although ABC Analysis is basically a matter of common sense, its formal application through a well laid out procedure, can attain maximum efficiency.*

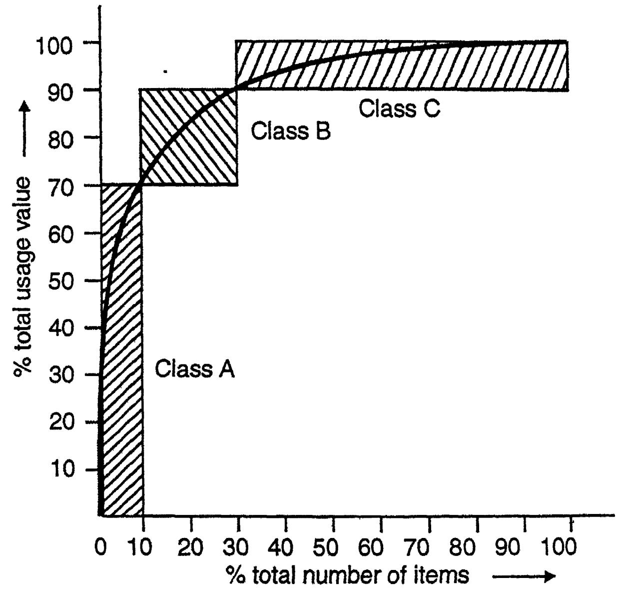


Fig. 21.7. Usage value classification of stock items.

In the field of materials management we are concerned mostly with purchasing, stores-inventory control and expenditing and follow up of purchase orders/requisitions. ABC analysis is eminently suited for use in this field.

Methods of pricing issue from stores. The methods of pricing the material to be issued from the stores are described below :

1. *First-in first-out method.* This method is also known as the *original cost method.* Item

first received into the stores are the first to be issued until exhausted. Materials are priced at the cost at which these items were placed in stock. This method is suitable for those industries where stocked items do not move very fast and have a high unit cost.

2. *Fixed prices method.* A fixed price is charged for each article issued but an adjustment account is opened for necessary adjustment of price of an article. This system may prove useful when market trend exhibits steady level and is used in connection with standard costing procedure.

3. *Average price method.* This method is further classified as :

(*i*) Simple average method.

(*ii*) Weighted average method.

(*iii*) Moving average method.

- In *simple average method,* the simple average of unit price is calculated by dividing the total of all unit pieces by the number of invoices, the quantity on each invoice being ignored.
- The *weight average method* involves the following procedure :

  (*a*) Total quantity received to total quantity on hand is added.

  (*b*) Cost of materials received to the cost of those on hand is added.

  (*c*) Total values are divided by total quantities to get the weighted average.

This system is used by those organisations which like to spread total costs uniformly over all goods on hand.

- The *moving average method* is a variation of the weighted average method. It is most suitable for application when there is a frequent fluctuations in the price of raw material and is considered desirable to bring uniform charges to working-process.

4. *Last-in first-out method.* This method is also known as the *replacement cost method.* Its basis are that the last items purchased are the first to be issued, the stock on hand being charged at the cost of the earliest purchases.

21.8. MATERIALS HANDLING

Material handling may be defined *as an art and science of the moving, packing and storing of substance in any from.* The various principles of economic materials handling are :

1. Reduction in line.
2. Reduction in handling.
3. Equipment design.

Types of material handling equipments:

The material handling equipments may be classified as follows :

1. *Horizontal fixed path equipment :*

(*i*) Band and belt conveyors.

(*ii*) Roller conveyors.

(*iii*) Slat and cross bar conveyors.

(*iv*) Vibrating conveyors.

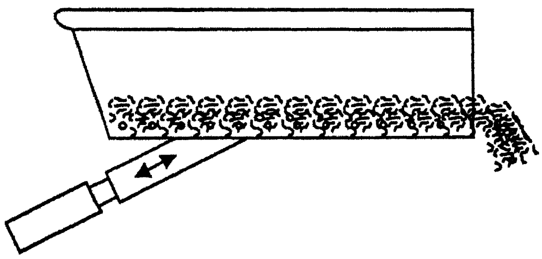


Fig. 21.8. Vibrating conveyor.

2. *Vertical movement :*
   (*i*) Bucket elevators.
   (*ii*) Roller spiral conveyor.
   (*iii*) Lifts.
3. *Overhead movement :*
   (*i*) Chain conveyors
   (*ii*) Cranes.
4. *Combined vertical and horizontal movement:*
   (*i*) Flight conveyors.
   (*ii*) Pneumatic conveyors.
5. *Horizontal non-fixed path equipment :*
   (*i*) Hand trucks
   (*ii*) Power trucks.

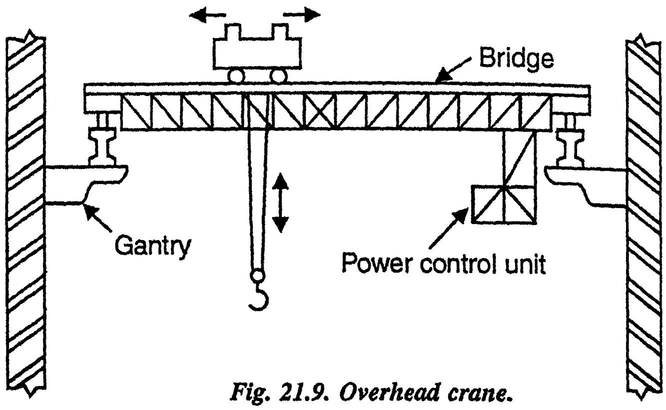


Fig. 21.9. Overhead crane.

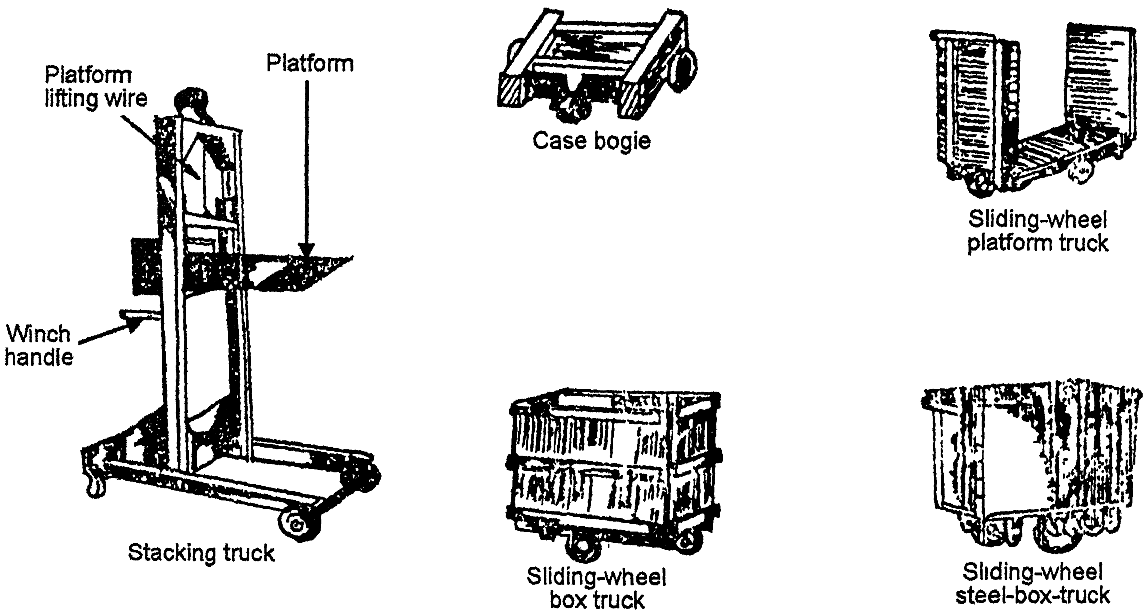


Fig. 21.10.

21.9. FINANCIAL MANAGEMENT AND BUDGETING

- *Finance* can be said as an activity concerned with planning, raising, controlling and administering of funds used in the business.
- The scope of financial management consists of the following activities :
  (*i*) Estimating the requirements.
  (*ii*) Determining the capital structure.
  (*iii*) Sources of funds.

(*iv*) Utilisation of funds.
(*v*) Disposal of surplus.
(*vi*) Management of cash.
(*vii*) Financial controls.

- *Financial planning* refers to planning the requirements of finance, the sources from which it is to be raised and the application of funds. It involves decisions like :
  (*i*) Capitalisation.
  (*ii*) Capital structure.
  (*iii*) Capital budgeting.
  (*iv*) Divided policy.
  (*v*) Credit and collection.
- A *sound financial plan* should satisfy the following requirements :
  (*i*) Simplicity.
  (*ii*) Flexibility.
  (*iii*) Economy.
  (*iv*) Availability of adequate funds.
  (*v*) Liquidity.
  (*vi*) Solvency.
  (*vii*) Provision of contingencies.
  (*viii*) Optimum use of funds.
- While formulating financial plans the main factors that need consideration are :
  (*i*) Objectives.
  (*ii*) Nature and size of business.
  (*iii*) Status of enterprise.
  (*iv*) Growth and expansion plans.
  (*v*) Attitudes of management.
  (*vi*) Capital market trends.
  (*vii*) Government regulations.
- Some common sources of raising finances are :
  (*i*) Industrial banks.
  (*ii*) Unit trust of India.
  (*iii*) Industrial Finance Corporation of India.
  (*iv*) Life Insurance Corporation of India.
  (*v*) Industrial Development Bank of India.
  (*vi*) Shares.
  (*vii*) Debentures.
  (*viii*) Mutual Funds.

"Budgetary control" is the process of *defining desired performance through the preparation of budgets, measuring and comparing actual results with the corresponding budget data for taking of appropriate actions to correct deviations if any.*

- Budgets may be *classified* as follows :
  A. 1. Fixed budget 2. Variable budget
  B. 1. Main budget 2. Master budget
  3. Subsidiary budget
- Sales budget, production budget, capital expenditure budget, materials and purchase budget, labour budget, selling and distribution cost budget, cash budget etc.

21.10. NETWORK ANALYSIS

Network analysis is a *system which plans projects both large and small by analysing the project activities.* It helps designing, planning, co-ordinating, controlling and in decision-making in order to accomplish the project economically in the minimum available time with the limited available sources.

Programme Evaluation and Review Technique (PERT). *It is a time event network analysis technique designed to watch how the parts of a programme fit together during the passage of time and events. This technique involves the application of network theory of scheduling problems.*

Project planning network. It is another name of PERT, which depicts the sequence of activities necessary to complete a project.

Event. It is a specific instant of time which marks the start and end of an activity.

Activity. It is an element of a project. It may be a process, material handling or material procurement cycle.

Critical path. It is the sequence of activities which decides the total project duration.

Total time. It is the time taken to complete a project. It is found from the sequence of critical activities.

Network diagram. It represent all the events and activities in sequence along with their interrelationship and interdependencies.

Bar chart. *It deals with complex activities.* It was developed by Henry Gantt in 1900.

Gantt progress chart. *It is used to make comparison between the actual and planned performance.*

Critical Path Method (CPM). It is highly similar to PERT. It is essentially an *arrow diagramming technique employing the concept of critical path and integrating all the usual factors of production, land, labour and capital.*

PERT uses *event-oriented network diagram* while **CPM** *uses activity oriented network diagram.*

21.11. OPERATION RESEARCH (OR)

- *Operation research* is the application of scientific methods, techniques and tools to problems involving the operations of a system so as to provide those in control of the system with optimum solutions to problems.
- *Operation research* is carried out to solve a large number of problems.
- The procedure involved in operation research involves the following *seven phases :*
  (*i*) Formulating the problem.

(*ii*) Collecting the data.
(*iii*) Constructing a mathematical model to represent system under study.
(*iv*) Deriving a solution from the model.
(*v*) Testing the model and the solution so derived.
(*vi*) Establishing controls over the solution with any degree of satisfaction.
(*vii*) Putting the solution to work, *i.e.*, implementation.

- Applications of 'operation research' are innumerous. It can be applied to almost all engineering problems.
- The various methods used in 'operation research' can be divided into the following two categories :
  (*i*) Deterministic models (*ii*) Probalistic models
- **Linear programming.** *It is a classical operation research technique* that was primarily used for military applications during World War II.
- The linear programming techniques can be classified as follows :
  (*i*) Graphical linear programming.
  (*ii*) Transportation method: (*a*) Vogel's approximate method, (*b*) North-west corner method.
  (*iii*) Simplex method.
- **Waiting line or queuing theory** *is used to examine the problem of waiting and minimising the waiting period.*
- *Simulation and Monte Carlo Technique* is a quantitative technique used for evaluating alternative courses of action based on facts and assumptions, with a mathematical model representing actual decision-making under conditions of uncertainty.

21.12. MAN POWER PLANNING AND CONTROL

- Manpower training, according to Vetter, is defined as *"the process by which the management determines how the organisation should move from its current manpower position to its desired manpower position."*
- Manpower planning should be scientific, need based and must be done well in advance.
- The various factors that need consideration in manpower planning are hours of working, number of shifts, type of production, product mix and performance rate.
- Manpower planning is an important activity as it provides plans for the recruitment, selection, placement and promotion of employees.
- *Span of control* is said as the number and range of direct habitual communication contacts between chief executive of an enterprise and his principal fellow officer. Its main objective is as to how many persons should a supervisor in an industry supervise.
- **Recruitment** refers to the discovery and development of the sources of required personnel so that sufficient number of candidates will always be available for employement in the organisation.
- **Training** of employees for specific job is necessary to bring the employee to the standards where he can carry out the industrial activity successfully.

21.13. FORECASTING

Forecasting means estimation of type, quantity and quality of future work.

Purpose or need of forecasting :

Sales forecasting is *essential* because;

(*i*) It determines the volume of production and the production rate.
(*ii*) It forms basis for production budget, labour budget, material budget etc.
(*iii*) It suggests the need for plant expansion.
(*iv*) It emphasizes the need for product research development.
(*v*) It suggests the need for changes in production methods.
(*vi*) It helps establishing pricing policies.
(*vii*) It helps deciding the extent of advertising, product distribution, etc.

Forecasting techniques :

Following *techniques are used for forecasting* :

(*i*) Historical estimate
(*ii*) Estimation by salesmen
(*iii*) Statistical analysis
(*iv*) Moving average data method
(*v*) The exponential smoothing method
(*vi*) Market research by suitable questionnaire
(*vii*) Survey or buyer's views
(*viii*) Collective opinion.

21.14. MANAGEMENT INFORMATION SYSTEMS (M.I.S.)

- Management information system aims at providing reliable information to the management to take timely, sound and accurate decisions. The system should be flexible and capable of updating quickly.
- A few important steps involved in the design of M.I.S. are as follows :

1. **Analysis :**
   (*i*) Problem recognition
   (*ii*) Problem identification.
2. **Synthesis of problem :**
   (*i*) Preparation of flow chart.
   (*ii*) Examination of information documents.
   (*iii*) Working out quantities.
   (*iv*) Establishing inputs and outputs.
   (*v*) Assigning the tasks and responsibilities.
   (*vi*) Running in parallel.

- M.I.S. is necessary to take decisions. Decisions are taken at every stage but what is to be ensured is that decisions should be timely and practical.

Desirable Characteristics of Management Information System (MIS) :

Following are the desirable characteristics of MIS :

- It *should be able to generate information* for identifying alternatives and then selecting an alternative based on laid down criteria.
- It *must help in planning* of end results and must throw up as to what specific activities are required to achieve these.
- It should have an *in-built system* of measuring own and subordinate's performance, pinpoint responsibility and indicate the corrective action.
- It should be *comprehensive* and cover all aspects of organizational activities.
- It should help in *achievement of objectives* of *organisation.*
- It should concentrate on developing information rather than facts. Only relevant information should be provided while irrelevant information is omitted.
- The information flow should follow organisation structure and should keep in view the delegation of various authorities.

- It must be an *integrated system* from which qualitative information for higher-level of management can be easily extracted.
- It *should identify the differential needs of information for planning and control* and develop both the types together.
- Data generated must be timely, cover past, present and future anticipation.
- It is preferable to use common data to the fullest extent on a simple format which satisfies maximum number of personnel.
- It should dovetail high level human communication which is indispensable for any information system.
- Information collection and flow should be designed keeping the managerial styles in view.
- It *must achieve appropriate and full utilisation of computer.*
- The system should provide for continuous reviewing.

HIGHLIGHTS

1. Maintenance can be classified as follows :
   (*i*) Preplanned maintenance; (*ii*) Breakdown or corrective maintenance;
   (*iii*) Preventive maintenance; (*iv*) Schedule maintenance.
2. *Time study* is the analysis of a job for the purpose of determining the time it should take a qualified person working at a normal face, to do a job using a definite and prescribed method. This time is called *standard* time for the operation.
3. *Motion study* is a management technique linking motion to each other in such scientific way that bodies and mental fatigue may be eliminated.
4. *Merit rating* is the process of evaluating the employee performance or the job in terms of requirements of the job.
5. *Inventory control* refers to the physical vertification of the stock in the stores, intended to determine the state of affairs of the store organisation.

OBJECTIVE TYPE QUESTIONS

Fill in the Blanks or Say 'Yes' or 'No' :

1. Cleanliness directly helps in tracing cracks and other defects.
2. The aim of .... maintenance is to avoid breakdown.
3. .... factor is also known as 'Levelling factor'.
4. .... study is defined as the science of eliminating wastefulness resulting from unnecessary, ill directed and inefficient motions.
5. A .... chart is an aid to the visualisation of the movement of the materials on an existing floor layout.
6. A .... chart is a record of the simultaneous activities of men and machines.
7. Gilbreth introduced certain elements called .... to indicate human movement.
8. .... is the process of evaluating the employee performance on the job in terms of requirements of the job.
9. The wages that are sufficient to meet the basic necessities of life, are known as .... wages.
10. Centralised stores are used in large industries.

11. .... includes not only those materials and supplies but also machinery spares or other items which are subject to yearly depreciation charges.
12. Inventory control must be fluid, must adjust rapidly to external forces.
13. The .... order shows how much to order.
14. .... can be said as an activity concerned with planning, raising, controlling and administering of funds used in the business.
15. Network analysis is a system which plans projects both large and small by analysing the project activities.

ANSWERS

1. Yes	2. schedule	3. Rating
4. Motion	5. flow	6. man-machine
7. therbligs	8. Merit rating	9. fair
10. No.	11. Inventory	12. Yes
13. standard	14. Finance	15. Yes

THEORETICAL QUESTIONS

1. Explain briefly any two of the following types of maintenance :
   (*i*) Preplanned maintenance
   (*ii*) Breakdown or corrective maintenance.
   (*iii*) Preventive maintenance.
   (*iv*) Schedule maintenance.
2. What do you mean by 'work study' ? Explain.
3. List the steps involved in 'Method study'.
4. What is 'time study' ? What are its objectives ?
5. Describe brief 'Motion study'.
6. What is micromotion study ? Explain.
7. What are 'therbligs'?
8. Explain briefly the following terms :
   (*i*) Job analysis, (*ii*) Job evaluation, (*iii*) Merit rating
9. Give the classification of wage payment plans.
10. Describe briefly the following wage payment plans :
    (*i*) Time rate system.
    (*ii*) Piece rate system.
11. List five non-financial incentives.
12. What do you mean by 'Contralised purchasing' ?
13. What is 'Inventory control' ? What are its objectives ?
14. What is 'Economic Ordering Quantity' ?
15. Explain briefly 'ABC analysis'.
16. Write a short note on 'Materials handling'.
17. What is 'Network analysis' ? Explain.
18. Define the following terms :
    Event; Activity; Critical path; Total time.
19. Write a short note on Operation Research (OR).
20. Explain briefly 'Management Information Systems' (MIS).
21. State the desirable characteristics of MIS.

QUESTIONS' BANK

A. SHORT ANSWER QUESTIONS

B. OBJECTIVE TYPE TEST QUESTIONS

(*Questions selected from A.M.I.E. and Universities Exams.*)

I. Choose the Correct Answer.

II. Fill in the Blanks with Appropriate Answer from the Set.

III. Fill in the Blanks.

A. Short Answer Questions

Q. 1. How NC machines differ from general class of machine tools?

Ans. Numerical control regulates machine tool movements by numbers which are converted into electric impulses to drive the lead screw for feeding movements. *N/C metal working machines do not have handwheels for operators but servomotors which drive the machine tool slides.*

Q. 2. What is the difference between NC and CNC machines?

Ans. NC machines differ from CNC in the sense that NC (Numerical Control) machines are *driven by punched tape.* On the other hand CNC (Computer Numerical Control) machine *depend upon computer programs to obtain motions to drive motor.*

Q. 3. Differentiate between DNC machines and CNC machines.

Ans. DNC (Direct Numerical Control) machine tools use *one master computer to drive a number of machine tools.* On the other hand CNC *uses one separate computer for each machine tool.*

Q. 4. Differentiate between 'hot working' and 'cold working'.

Ans. Hot working and cold working differ from one another in the temperature at which the deformation is carried out. A process is paid to be a *hot working process* when the working temperature *exceeds recrystallisation temperature.*

Q. 5. Compare the strength of a welded joint w.r.t. the strength of parent material.

Ans. The strength of a welded joint should be *greater than or equal to that of the parent metal.*

Q. 6. How carbide tools are fitted to the tool shank ?

Ans. Carbide tools are fitted to tool shanks by brazing method or by clamping with screw.

Q. 7. What is quality audit?

Ans. Quality audit is a quality control procedure in which strict quality inspection is carried on every stage of production. Quality audit has attained great importance with industries desiring ISO 9000 accredition.

Q. 8. Differentiate between continuous and discrete production.

Ans. Continuous production is *either flow shop type or mass production* in very large quantities in a single set-up. On the other hand *discrete production is production in batches or lots.*

Q. 9. List two reasons for using sampling plan against 100% inspection.

Ans. (*a*) Avoiding monotony.

(*b*) When destructive method of inspection is followed, sampling is a must.

Q. 10. What are the main constituents of a core sand?

Ans. Core sand is green sand which contains sand and clay with water. Oil or organic substances are used to improve the bonding properties of core sand.

Q. 11. What is morphological analysis in the design?

Ans. Morphological analysis in design is *one of the techniques of generating alternative design proposals by using a Matrix approach.* The matrix has design criteria as a variable and feasible solutions as the other.

Q. 12. Give one example of input-output model.

Ans. In an automobile industry, castings, forgings, sheetmetal parts etc. are material inputs, the other inputs being labour, machines and capital. The desirable output is in the form of automobile benefit to society whereas pollution represents undesirable output. Metal cutting, metal forming, painting, assembly and inspection represent value adding between input of control when using $\overline{X}$-chart.

Q. 13. What is fail safe design?

Ans. *Fail safe design ensures that the design in question will not operate until the operator is safe.* If the operator is in a potentially dangerous configuration the machine cannot be operated.

Q. 14. Plate moulding is suitable for producing large quantities of simple castings? *Give reasons.*

Ans. Plate moulding uses a metallic plate having half of the pattern on one side of plate and rest on the other side. *Match plate type pattern has several small patterns screwed on the plate to increase productivity.*

Q. 15. What for an Automated Guided Vehicle (AGV) is used?

Ans. Automated Guided Vehicles are used in *flexible manufacturing systems (FMS) for material handling between machine tools which are driven by a master computer alternatively, conveyors are used.*

Q. 16. What is the role of 'FIT' in engineering design?

Ans. Fit is very important aspect in design and determines clearance between two parts. A clearance fit is recommend for shaft bearing combination. A transition fit is used for location of one part with respect to other. A press fit is used for rigid fit between two parts, *e.g.*, a gear on a shaft (in some cases).

Q. 17. Hard metals are easily machined in ECM. *Give reasons.*

Ans. Hard metals are easily machined by ECM because ECM depends upon current and time according to laws of electrolysis.

Q. 18. Differentiate between inspection and quality control.

Ans. '*Inspection*' is process of checking quality with a view to determining defectives or modificatives whereas '*quality control*' involves processing of inspection data. After evaluation of the quality, a feedback is done to review design, process or assignable causes of quality variation.

Q. 19. When do we get discontinuous chips?

Ans. Discontinuous chips are obtained *during cuttings of brittle work materials or during cutting of ductile materials under poor cutting conditions such as high chip tool friction, low rake angle, low shear plane angle and slow cutting speed.*

Q. 20. Give two criteria for the process being out of control when using $\bar{X}$ chart.

Ans. (*a*) Shift in the process mean;

(*b*) Trend indicating increase in $\bar{X}$.

Q. 21. Communication gap usually causes heavy financial loss in the business. ***Give reasons.***

Ans. Communication gap between customer and marketing people, between marketing and design, between design and production and distribution etc. create unsynchronised production and financial losses.

Q. 22. List the hierarchy of human needs that motivate individuals.

Ans. (*i*) Affliation need; (*ii*) Esteem need; (*iii*) Actualization need.

Q. 23. Engine crankshafts are forged and not cast. ***Give reasons.***

Ans. *Forging is preferred for giving proper grain flow lines and increased strength.* Castings cannot provide the needed strength.

Q. 24. What is Just in Time (JIT) manufacturing?

Ans. Just in time (JIT) is a manufacturing philosophy in Japan which results in high efficiency through zero inventories, zero defect, zero lead time, (JI Purchang) (Pake Yoke) load smoothing, kanban (pull system) and zero set up times (through single minute exchange of dies).

Q. 25. Differentiate between a 'Boring head' and a 'Boring bar'.

Ans. A '*boring head*' is a device for *orginating a hole* in a solid whereas a '*boring bar*' has a bit fitted to it *for fine finishing a hole.*

Q. 26. Process capability studies are important in production. ***Give reasons.***

Ans. Process capability 'Six Sigma' enables the selection of proper machine for achieving given Tolerance grade. Ratio (Tol/6σ) is called Relative Precision Index. Its value should be approximately 1.5 to 2.

Q. 27. Market research is necessary before starting the production of any product. ***Give reasons.***

Ans. Market research is responsible for identities the need of people. Before a needs' analysis is done it is not possible to arrive at design specifications and production start up.

Q. 28. List advantages of forging compared to machining in obtaining component shapes.

Ans. A forging has the following desirable properties as compared to a machined part :

(*i*) Macroscopic grain flow lines which make a forging *stronger.*

(*ii*) Superior grain structure.

(*iii*) Better strength due to directional property.

Q. 29. For what purpose Electric Discharge Machines (EDM) are used?

Ans. EDM machines are used for avoiding difficulty to machine materials through use of electric spark. Examples are Die sinking or removal of broken tools embedded in workpieces

Q. 30. Name bases for part coding in group technology.

Ans. Bases for part coding in group technology are :

(*i*) Production Flow Analysis (PFA) which decides the processing sequence for components belonging to a group; (*ii*) Monocode system (*e.g.*, Optiz system); (*iii*) Polycode system; (*iv*) Hybrid system.

Q. 31. Environmental factors affect the design of a production system. ***Give reasons.***

Ans. When a product is to operate in an aggregate environment, special care is to be exercised in material selection. Efficiency of a design at the rated value depends upon environmental factors.

Q. 32. Name the two safety devices which are generally used in machine design.

Ans. (*i*) Enclosing an electrical gadget in a shock proof enclosure;

(*ii*) Placing a pulley drive in a cage on certain machine tools.

Q. 33. Explain in short "Control charts and their use".

Ans.
- **A control chart** *is a simple graphical device for knowing at a given instance of time whether or not a process is under control.*
- In any manufacturing process there in some variation from piece to piece. A control chart is simply a frequency distribution of the observed values processed as points in order of occurrence so that each value has its own identity relative to the time of observation. Points on the charts may or may not be connected. The chart is provided with limit lines called control limits, having in general, one *upper limit* and one *lower control limit.*

Q. 34. What is maintainability criteria is design?

Ans. Maintainability criteria in design aims at designing with a view to have a product which can be maintained with ease, *high maintainability results in greater availability of the machine.*

Q. 35. Under what criteria, reliability allocation is made?

Ans. Reliability allocation consists of *assigning realistic numerical values to reliability of components which from the parts of a system.* The various criteria for component reliability allocation are : (*i*) Meeting overall system reliability goal; (*ii*) Allocating reliability values to components based on actual life testing in such a way that the theoretical reliability figure is kept less than test value. A reasonable value of component reliability ensures good repairability and maintainability; (*iii*) Availability—is another criterion; (*iv*) Cost-achievement of system reliability at minimum cost is another criterion.

Q. 36. Distinguish between 'Functional design' and 'Industrial design'.

Ans. '*Functional design*' aims at *achieving a design system which will just perform the function.* '*Industrial design*' focuses on *aesthetic aspect of appearance of the product.*

Q. 37. List three reasons for using single sampling plan for inspection of items.

Ans. (*i*) It is easy to design, explain and administer.

(*ii*) It involves lower cost of training and supervising employees, transporting and sorting samples.

(*iii*) It estimates lot quality very accurately.

Q. 38. Why are risers not used in die casting?

Ans. Risers are not used in die casting due to chilling effect facilitated by die.

Q. 39. Indicate the source of energy in the following process:

(*a*) EDM, (*b*) USM, (*c*) LBM, (*d*) ECM

Ans. (*a*) EDM → *Electric spark*; (*b*) USM → *Mechanical*;
(*c*) LBM → *Radiation*; (*d*) ECM → *Electrical.*

Q. 40. Differentiate between production and productivity.

Ans. '*Products*' are manufactured by the transformation of raw material (into finished goods). This is how production is achieved and '*productivity' is ratio of output and input.*

Q. 41. What are the major function of a cutting fluid?

Ans. The *major functions of cuttng fluid are :*

(*i*) It acts as a coolant.

(*ii*) It acts an a lubricant.

(*iii*) It improves machinability.

(*iv*) It improves surface of product.

(*v*) It increases tool life.

Q. 42. Define quality control and quality assurance.

Ans. '*Quality control*' is a system for *measuring and checking of the quality characteristics* and *quality assurance is the certainty of attaining a particular quality level.*

Q. 43. Give two applications of linear programming problem in manufacturing.

Ans. (*i*) Aggregate planning; (*ii*) Product mix decisions.

Q. 44. What is the main source of heat in metal cutting?

Ans. *Shear zone* is the main source of heat at cool chip contact area in metal cutting.

Q. 45. Indicate the type of production system most relevant to

(*a*) Steel production; (*b*) Automobile production;

(*c*) Repair and maintenance work; (*d*) Manufacturing of nuts and bolts.

Ans. (*a*) Steel production → *Continuous production system.*

(*b*) Automobile production → *Mass and flow production system.*

(*c*) Repair and maintenance work → *Job order production.*

(*d*) Manufacturing of nuts and bolts → *Continuous or process production system*

Q. 46. Define ranges of cold and hot working in terms of melting point of materi being formed.

Ans. Cold working is done at temperature below recrystallization temperature. Hot workin is done above recrystallization temperature.

Q. 47. What types of models are used in design?

Ans. In design three types of models are used :

(i) *Physical or Iconic models.* These give the designer and the concerned staff an idea of the actual product. Aerodynamic testing is possible with scale models.

(ii) *Mathematical models.* These help designer to use CAD facility for stress and strength analysis and compatibility of parts.

(iii) *Analogue models.* These models enable similitude between sensitivity and robustness.

Q. 48. What is the relationship between arc length and voltage in arc welding?

Ans. The relationship between arc length and voltage is given by a linear equation:

$$V = a + bl$$

where, V = The voltage,

l = Length of arc, and

a, b = Constants (depending upon electrode material and atmosphere surrounding the arc.

Q. 49. What is the difference in draft requirements between sand casting and shell moulding?

Ans. Shell moulding needs negligible draft as compared with sand mouldings.

Q. 50. What is computer-aided design?

Ans. *Computer aided design involves the use of computers to create design, drawings and product models.* It is usually associated with *interactive computer graphics* (known as **CAD system**). Computer-aided design systems are powerful tools and are used in the mechanical design and geometric modelling of products and components.

Q. 51. What is die-casting?

Ans. The die-casting is produced by forcing molten metal at high pressure into a split steel die cavity and this pressure is maintained till solidification stage. Die-casting is most widely used for permanent mould processes.

Q. 52. What is 'design standard'?

Ans. *'Design standards' are the specified dimensions and sizes of parts like scours and bearings, the minimum properties of materials, or the allowable discharge of pollutants.* Other standards usually include design codes, prescribed methods of analysis and calculation for certain routine design problems.

Q. 53. What are advantages of hot working?

Ans. During all hot working operations the metal is in plastic state and readily formed by pressure so *energy requirement is less*. In hot working *porosity in metal is largely eliminated. Blow holes* are very small and they are pressed together and *eliminated, coarse grains are refined and physical properties are generally improved.*

Q. 54. Explain in short, the bond formation in brazing.

Ans. Bond is formed during brazing between filler metal and base metal, this bond is possible because filler metal has melting point lower than the base metal which does not fuse.

Q. 55. Differentiate between 'neutral flame' and 'oxidising flame'.

Ans. *Neutral flame* is produced when $O_2 : C_2H_2 \rightarrow 1 : 1$. It is obtained by supplying equal volumes of oxygen and accetylene.

Oxidising flame is produced when $O_2 : C_2H_2 \geq 1.5 : 1$. It is obtained with an excess of oxygen above that required for chemical reaction.

Q. 56. Explain 'Engineering design'.

Ans. *'Engineering design' is an intellectual attempt to meet certain demand in the best and economical way.* It is an engineering activity that impriges on nearly every sphere of life, relies on discoveries and laws of science, and creates the conditions for applying these laws to the manufacture of useful products.

Q. 57. What do you understand by 'Intution'?

Ans. '*Intution*' means sudden ideas (flashes of inspiration) and involves complex association of ideas, elaborated in subconscious mind. Intution ideas lead to a large number of good and even excellent solutions.

Q. 58. What for thermit welding is used?

Ans. Thermit welding is used to weld thick sections like railway girders together.

Q. 59. What is specified by 'specification'?

Ans. *'Specification' specify detailed description of the required characteristics (qualified and unquantified) of a device, system or process.* A specification can be drawn up after the design drawings are completed.

Q. 60. What is database management system?

Ans. Database management system (DBMS) is a *computer software to facilitate the automated support of data storage and access activities of database* .

Q. 61. Explain very briefly 'Methodology for robust design'.

Ans. Robust design methodology *serves as an amplifier, i.e.,* it enables an engineer to generate information needed for decision making with half (or even less) the experimental effort.

Q. 62. Explain briefly 'Design for economic manufacturing'.

Ans. It involves selection of best production and process topology to reduce the cost of components and manufacturing processes to minimum keeping in view the quality and standard of the product.

Q. 63. What is 'Quality Assurance'?

Ans. Quality assurance is one of the basic assurance technologies which incorporates customer satisfaction requirements in design and controls of manufacturing defects. *'Quality assurance' is defined as a series of planned or systematic actions required to provide adequate confidence that a product or service will satisfy given needs.*

Q. 64. What is recrystallisation temperature?

Ans. Recrystallisation temperature is a temperature above which dislocation free and new grains emerges from a material that was previously cold worked. This depends upon the extent of cold work, time of heat treatment. etc. Recrystallisation temperature is not a fixed temperature.

Q. 65. What are 'Automated guided vehicles'?

Ans. *The vehicles that interface with workstations for automatic or manual loading and unloading alongwith industrial robots are known as* **automated guided vehicles** (AGV) These are used extensively in flexible manufacturing system to move parts and orient them as required.

Q. 66. Explain very briefly 'Laser sources'.

Ans. The term laser is an acronym for "light amplification by simulated emission of radiation". Simply stated *it is very strong monochromatic beam of light that is highly collimated and has a very small beam divergence.* Laser sources are widely used in manufacturing such as welding, machining etc.

Q. 67. What is 'soldering'?

Ans. It is the joining of metals by means of a fusible metal or alloy (in molten state) called solder. The joining is effected by adhesion between the solder and the parent metal. This process is carried out at temperatures less than 300°C. Soldering is used to joint steel metals such a tin cars and duct work and for numerous electronic applications.

Q. 68. Explain very briefly 'User friendly designs'.

Ans. This is a type of design which helps and supports the user of product. User friendly design concepts are fast gaining popularity by the fact that consumers are now dictating the market of any product. User friendly designs help the product for more revenue and keep the market alive for many years.

Q. 69. What are 'computer peripherals'?

Ans. Any hardware item that is attached to the main unit (CPU) of a computer is referred to as peripheral device. All the input and output devices attached to CPU are *peripheral devices.* Input devices include; keyboard, scanners, pointing devices and digital camera etc Output devices include monitor and printers.

Q. 70. What do you understand by need analysis?

Ans. Through market survey and market research (analysis) need for product is identified. The need is stated in primitive terms in the form of 'Preliminary Needs Statement'. The need statement does not immediately converge to suggest a single design but it encourages multiple solution and idea generation.

Q. 71. Environmental factors affect the design of a production system. ***Give reasons.***

Ans. Noise is a disturbing factor for the human body. It has undesirable effect on the ear drum which may lead to deafness. Noise also affects the nervous system which may result in complications relatively to circulation, blood pressure and cardiac problems. Noise affects concentration and prevents the operator from giving consistent and accurate production.

Q. 72. For smaller groove side welding the cost is low. ***Give reasons.***

Ans. For smaller groove side welding the cost is low because of material saving of electrode as well as energy savings due to less energy expenditure at the arc.

B. Objective Type Test Questions

I. Choose the Correct Answer :

1. **The down spruce in casting is given a tapered shape for**
   (*a*) easy flow of molten material
   (*b*) easy withdrawal of casting
   (*c*) preventing aspiration of gases through spruce
   (*d*) preventing bulging of spruce during pouring.
2. **Which of the following is a medium grade grinding wheel with open structure?**
   (*a*) A 46–Q 6–V 10 (*b*) A 46–G 4–V 10
   (*c*) A 46–K 10–V 10 (*d*) A 46–R 12–V 10.
3. **'Misrun' is a casting defect which occurs when**
   (*a*) the pouring temperature is very high
   (*b*) gases have been absorbed by the liquid metal
   (*c*) sufficient superheat has not been provided to the liquid metal
   (*d*) the alignment is improper.
4. **In gas welding the highest temperature is obtained with a**
   (*a*) neutral flame (*b*) oxidizing flame
   (*c*) carburizing flame (*d*) any of these.
5. **In rolling operations the rolls rotate with a surface velocity**
   (*a*) lower than the speed of the incoming metal
   (*b*) exceeding the speed of the incoming metal
   (*c*) equal to the speed of the incoming metal
   (*d*) any of these.
6. **The front rake required to machine brass by high speed steel tool is**
   (*a*) 15° (*b*) 10°
   (*c*) 5° (*d*) 0°.
7. **The arbor of milling machine is used to hold**
   (*a*) cutting tool (*b*) spindle
   (*c*) mandrel (*d*) workpiece.
8. **In grinding operation for grinding harder material**
   (*a*) softer grade is used (*b*) high grade is used
   (*c*) medium grade is used (*d*) any grade may be used.

9. **Nominal diameter of bolt thread is same as**
   (*a*) major diameter (*b*) pitch diameter
   (*c*) minor diameter (*d*) none of the above.
10. **The advantage of vernier caliper over micrometer is because it**
    (*a*) is easier and quicker to use
    (*b*) is more accurate
    (*c*) can be used to make inside and outside measurements over a range of sizes
    (*d*) is not suitable for any of the above.
11. **Expressing a dimension as $18.3^{+0.00}_{-00.2}$ mm is the case of**
    (*a*) unilateral tolerance (*b*) bilateral tolerance
    (*c*) limiting dimension (*d*) None of the above.
12. **The metal in electro-chemical machining process is removed by**
    (*a*) ionization and shearing
    (*b*) transfer of electrons
    (c) chemical action and abrasion
    (*d*) migration of ions towards the tool.
13. **Which of the following welding processes uses non-consumable electrode?**
    (*a*) Laser welding (*b*) MIG welding
    (*c*) TIG welding (*d*) Plasma welding.
14. **Shellac bonded grinding wheels are most appropriate for**
    (*a*) surface grinding (*b*) cylindrical grinding
    (*c*) cut-off operations (*d*) thread grinding.
15. **Ultrasonic machining is used for efficient machining of**
    (*a*) ferrous materials (*b*) alloyed steels
    (*c*) aluminium (*d*) refractory materials.
16. **Porosity in thin sections of a casting can be minimized by**
    (*a*) changing progressive solidification to directional solidification
    (*b*) changing directional solidification to progressive solidification
    (*c*) providing risers with large area/volume ratio
    (*d*) use of open risers.
17. **In resistance welded parts**
    (*a*) heat affected zone is large (*b*) heat affected zone is small
    (*c*) joining relies on adhesion (*d*) require high operating voltage.
18. **In indirect extrusion process**
    (*a*) the container friction has significant influence on the product quality.
    (*b*) the container friction has no direct effect on product quality.
    (*c*) is associated with the formation of dead metal zone.
    (*d*) can be carried out at elevated temperatures only.
19. **One of the frequently used tools for concept design is**
    (*a*) QFD (*b*) Engineering analysis
    (*c*) Quality loss function (*d*) None of the above.

20. Variant type computer aided process planning is most useful when
(*a*) large number of part families are involved
(*b*) small number of part families with short product life cycles are involved
(*c*) small number of part families with fairly stable product life cycles are involved
(*d*) very complex parts.

21. Use of a stand-alone CNC machines is recommended for
(*a*) mass production of components
(*b*) small batch production
(*c*) production of components in a batch of 1–3
(*d*) complex parts in small numbers.

22. The mechanical design process normally has six stages and amongst them the three stages are ....
(*a*) start, middle and end
(*b*) CAD, CAM and DFM
(*c*) Recognising the need, definition of problem and synthesis
(*d*) electrical design, mechanical design and detailed drawing.

23. The detailed drawing of the component or product helps to result into ....
(*a*) bill of material (*b*) resource planning
(*c*) tool planning (*d*) machine planning.

24. The design of product is .... of customer expectations.
(*a*) symbols (*b*) manifestation
(*c*) colour (*d*) planning.

25. The factor of safety is applied to designing process to evaluate
(*a*) soundness (*b*) dimensions
(*c*) safeness (*d*) strains.

26. The design decision are made after evaluating several proposed designs in terms of ....
(*a*) value and cost (*b*) stress and strain
(*c*) cost and fatigue (*d*) hardness and brittleness.

27. Ergonomic factors are included in the product design to have ....
(*a*) comfort to user (*b*) comfort to manufacturer.
(*c*) comfort to user and manufacturer (*d*) comfort to tester.

28. If the feed is stopped and the cutter continues to rotate the cutter will .... in the metal.
(*a*) feed down (*b*) cut microsize chip
(*c*) vibrate (*d*) create heat.

29. The built-up edge with chip is formed when ....
(*a*) feed is coarse
(*b*) material is ductile
(*c*) friction at chip tool interface is high
(*d*) cutting speed is low.

30. The most suitable abrasive for grinding hard materials like ceramics and tungsten carbide is ....

(*a*) aluminium oxide (*b*) silicon carbide
(*c*) boron carbide (*d*) diamond.

31. Natural sand is used as the moulding sand mainly due to the fact that it is ....

(*a*) refractory (*b*) cheap
(*c*) easy availability (*d*) refractory and granular.

32. The tool life is presented in the form of ....

(*a*) $VT^n = C$ (*b*) $T^{2/n} = C$
(*c*) $T^{1/n} = C$ (*d*) $T^{1/n} V = C$.

33. The protective gaseous atmosphere around the arc and weld pool in case of arc welding is due to ....

(*a*) burning of air (*b*) burning of flux
(*c*) formation of metal vapours (*d*) none of these.

34. Electrode is consumed in .... welding.

(*a*) arc (*b*) tungsten-inert gas
(*c*) gas (*d*) thermit.

35. In chemical machining, the mechanics of material removal is ....

(*a*) corrosive reaction (*b*) plastic shear
(*c*) erosion (*d*) ion displacement.

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(*c*) comfort to user and manufacturer (*d*) comfort to tester.

42. If the feed is stopped and the cutter continues to rotate, the cuter will .... in the metal.

(*a*) create heat (*b*) cut microsize chip

(*c*) vibrate (*d*) feed down.

43. The build-up edge with chip is formed when ....

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(*c*) $V^{1/n}\,T = C$ (*d*) $T^{1/n}\,V = C$.

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(*a*) burning of air (*b*) burning of flux

(*c*) formation of metal vapours (*d*) none of these.

48. Electode is consumed in .... welding.

(*a*) tungsten-insert gas (*b*) arc

(*c*) gas (*d*) thermit.

49. In chemical machining, the mechanics of material removal is by ....

(*a*) corrosive reaction (*b*) plastic shear

(*c*) erosion (*d*) ion displacement.

50. The creative process can be viewed as moving from

(*a*) rough idea to well structured idea (*b*) choatic to the organised idea

(*c*) implicit to the explicit idea (*d*) all the above.

51. For enchancing the creative thinking one should be

(*a*) persistent (*b*) develop an open mind

(*c*) discard problem boundaries (*d*) both (*a*) and (*b*).

52. A creative engineer has

(*a*) curious and imaginative mind

(*b*) broad background of fundamental knowledge

(*c*) both (*a*) and (*b*)

(*d*) none of the above.

53. Angle between the toolface and the ground end surface of flank is known as

(*a*) lip angle (*b*) rake angle
(*c*) nose angle (*d*) clearance angle.

54. For soft material, point angle of drill is

(*a*) increased (*b*) decreased
(*c*) kept at 118° (*d*) unchanged.

55. Stud and projection welding refers to

(*a*) submerged welding (*b*) TIG welding
(*c*) pressure welding (*d*) resistance welding.

56. In straight polarity welding :

(*a*) electrode holder is connected to positive and work to negative
(*b*) electrode holder is connected to negative and work to positive
(*c*) work is negative and holder is earthed
(*d*) none of the above.

57. If the components are so arranged that the failure of any component causes the system failure, it is said to be arranged in ....

(*a*) series (*b*) parallel
(*c*) series-parallel (*d*) standby.

58. If the components are so arranged that the failure of all component causes the system failure, it is said to be arranged in ....

(*a*) series (*b*) parallel
(*c*) series-parallel (*d*) standby.

59. Angle between the face of tool and the line tangent to the machined surface at the cutting point is known as

(*a*) Rake angle (*b*) Lip angle
(*c*) Cutting angle (*d*) Nose angle.

60. Propositional calculus is used for

(*a*) analysis of complicated systems whose outputs and inputs have two states
(*b*) synthesis of complicated systems whose outputs and inputs have two states
(*c*) analysis and synthesis of any system
(*d*) both (*a*) and (*b*).

61. The rows in a truth table for n-variables formula are :

(*a*) 2^n (*b*) 3^n
(*c*) n (*d*) $2n$.

62. In arc welding, arc is created between electrode and work by

(*a*) flow of current (*b*) flow of voltage
(*c*) contact resistance (*d*) electrical energy.

63. Material used for coating the electrode is called

(*a*) protective layer (*b*) binder
(*c*) deoxidiser (*d*) flux.

64. Which of the following welding processes uses the non-consumable electrode?
(*a*) LASER welding
(*b*) MIG welding
(*c*) TIG welding
(*d*) Ion beam welding
(*e*) Plasma arc welding.

65. Liquid media should have
(*a*) good wetting properties
(*b*) high thermal conductivity
(*c*) low viscosity
(*d*) all of the above.

66. Feed mechanism of USM should perform the following function :
(*a*) Provide adequate cutting force and sustain this during cutting.
(*b*) Bring the tool very slowly close to the workpiece.
(*c*) Decrease the force at a certain depth.
(*d*) Overrun a small distance to ensure the required hole size at the exit and then return the tool.
(*e*) All of the above.

67. Copper is
(*a*) easily spot welded
(*b*) difficult to be spot welded
(*c*) either of the above
(*d*) none of the above.

68. Two sheets of same material but of different thickness can be butt welded by
(*a*) increasing the current
(*b*) increasing the voltage
(*c*) changing the size of the electrode
(*d*) none of these.

69. In cold chamber method of die casting
(*a*) high melting point metals can be cast
(*b*) low melting point metals can be cast
(*c*) die is kept hot by electrical heating
(*d*) none of the above.

70. Ferrous alloys are usually cast by
(*a*) cold chamber machine
(*b*) hot chamber machine
(*c*) die-casting machine
(*d*) none of the above.

71. Machinability tends to decrease with
(*a*) decrease in grain-size
(*b*) increase in grain-size
(*c*) increase in strain-hardening tendencies
(*d*) none of the above.

72. As cutting speed increases, the built up edge
(*a*) becomes smaller and finally does not form at all
(*b*) has nothing to do with speed
(*c*) becomes bigger
(*d*) none of the above.

73. Linear programming is used in solving optimisation problems that involves ....

(*a*) linear objective functions (*b*) non-linear objective functions
(*c*) both (*a*) and (*b*) (*d*) simplex objective functions

74. .... is performed in order to determine how the optimum solution is affected by a small change in the original.

(*a*) Search method (*b*) Linear programming
(*c*) Sensitivity analysis (*d*) Differential calculus.

75. Shell moulding is uneconomical for

(*a*) small castings (*b*) large scale production
(*c*) small scale production (*d*) all of these.

76. Die casting is not generally used for

(*a*) zinc based alloys (*b*) aluminium based alloys
(*c*) non-ferrous metals (*d*) cast iron.

77. Flash occurs on die casting on the

(*a*) parting surface of two dies (*b*) vents between the dies
(*c*) ejection pins (*d*) gating system.

78. A very well defined set of design goals are called

(*a*) Need analysis (*b*) Design specifications
(*c*) Detail design (*d*) None of these.

79. A product design specification is

(*a*) a document which contains all the facts related to the product outcome
(*b*) definition of the design problem
(*c*) performance goals only
(*d*) analysis of the need.

80. Some of the primary elements of product design specification are :

(*a*) Performance (*b*) Environment
(*c*) Manufacturing Facility (*d*) All of these.

81. Investment casting is also known as :

(*a*) Lost wax casting (*b*) Lost pattern casting
(*c*) Hot investment casting (*d*) Any of these.

82. The .... applies regression analysis to past cost data to identify the cost.

(*a*) experience (*b*) engineering analysis
(*c*) statistical method (*d*) none of these.

83. The .... is the time required to prepare for operation.

(*a*) set-up time (*b*) man time
(*c*) machine time (*d*) down time.

84. The responsibility of preserving and protecting the quality of the product rest with

(*a*) sales (*b*) purchasing
(*c*) packaging and shipping (*d*) product service.

85. The collection of activities through which the industry achieves fitness for use is termed as :

(*a*) Quality function (*b*) Morale function
(*c*) Management function (*d*) Purchasing function.

86. Riddle is

(*a*) a long, flat metal plate fitted with an offset handle
(*b*) used to make or repair corners in a mould.
(*c*) a round sieve
(*d*) none of the above.

87. Draft on pattern for casting is

(*a*) taper to facilitate its removal from mould
(*b*) shrinkage allowance
(*c*) increase in size of cavity due to shaking of pattern
(*d*) none of the above.

88. In rolling operations the rolls rotate with a surface velocity

(*a*) lower than the speed of the incoming metal
(*b*) exceeding the speed of the incoming metal
(*c*) equal to the speed of the incoming metal
(*d*) any of these.

89. Which is incorrect statement about results of hot working?

(*a*) Annealing operation is not necessary.
(*b*) Power requirement are low.
(*c*) Surface finish is good.
(*d*) None of the above.

90. Metals like lead and tin are hot worked at temperatures around

(*a*) room temperature (*b*) about 100°C
(*c*) 500-600°C (*d*) –100°C.

91. In four high rolling mill the bigger rollers are called :

(*a*) guide rolls (*b*) back up rolls
(*c*) man rolls (*d*) none of these.

92. An important part of designer's job is to organise, improve and transmit

(*a*) specifications (*b*) informations
(*c*) problems (*d*) advice.

93. .... may comprise of facts, data, knowledge or intelligence.

(*a*) Ideas (*b*) Statements
(*c*) Information (*d*) Specifications.

94. Draft on pattern for casting is

(*a*) shrinkage allowance
(*b*) identification number marked on it
(*c*) taper to facilitate its removal from mould
(*d*) none of the above.

106. During brainstorming session, the ideas given by the participants are recorded

(*a*) after review by the leader (*b*) without any modification
(*c*) based on its usefulness (*d*) after being discussed by the group.

107. Sample opinions toward a preliminary design are obtained by ....

(*a*) Team approach (*b*) Research method
(*c*) Survey methods (*d*) Brainstorming.

108. In Thermit welding, Iron oxide and Aluminium oxide are mixed in the proportion of

(*a*) 1 : 3 (*b*) 1 : 2
(*c*) 3 : 1 (*d*) any ratio can be used.

109. TIG welding is best suited for welding

(*a*) mild steel (*b*) stainless steel
(*c*) carbon steel (*d*) silver
(*e*) aluminium.

110. Stellite is the trade name for

(*a*) Non-ferrous cast alloys (*b*) Advanced ceramics
(*c*) Ferrous cast alloys (*d*) Any of these.

111. Throw away tips are used because

(*a*) initial cost is low (*b*) tool change is easier
(*c*) regrinding is not required (*d*) none of the above.

112. The average number of defectives is the product of the sample size and the

(*a*) average fraction defective (*b*) fraction defective
(*c*) defective (*d*) percent defective.

113. In sampling plans, N indicates :

(*a*) Sample size (*b*) Lot size
(*c*) Acceptance number (*d*) Rejection number.

114. A critical defect is that which is likely to result in

(*a*) hazardous conditions
(*b*) failure to use the product for its intended purpose
(*c*) the reduction of usability of the product
(*d*) continuous usual performance.

115. A good designer must .... the ideas as they are generated but must record as many ideas as possible.

(*a*) evaluate (*b*) not evaluate
(*c*) develop (*d*) discuss.

116. In ...., many specialists of different areas work together towards a common goal.

(*a*) team approach (*b*) individual approach
(*c*) research method (*d*) survey method.

117. The ultimate unit of product of material on which inspection will be performed is known as

(*a*) Lot (*b*) Item
(*c*) Article (*d*) Sample.

118. A group of items drawn from a lot of inspection is called

(*a*) Lot size (*b*) AQL
(*c*) Sample size (*d*) Acceptance number.

119. In abrasive jet machining (AJM), metal removal takes place due to

(*a*) grinding (*b*) metal erosion
(*c*) machining (*d*) all of these.

120. Gears are best mass produced by :

(*a*) Milling (*b*) Hobbing
(*c*) Casting (*d*) Forging.

121. In press operation, size of the pierced hole is dependent on the size of :

(*a*) Punch (*b*) Die
(*c*) Clearance of die and punch (*d*) Average of die and punch diameter.

122. Optimisation is the process of :

(*a*) maximisation of a desirable quantity
(*b*) minimisation of an undesirable quantity
(*c*) both (*a*) and (*b*)
(*d*) analysis on an engineering problem.

123. It is .... to optimise always an engineering problem.

(*a*) possible (*b*) not possible
(*c*) may be possible (*d*) none of these.

124. Optimisation by .... involves improving existing designs or products.

(*a*) evolution (*b*) intuition
(*c*) analytical methods (*d*) both (*a*) and (*b*).

125. The .... search method can be used to optimise objective functions with more than two variables.

(*a*) uniform (*b*) sequential
(*c*) sequential simplex (*d*) golden section.

126. A degree of difficulty in geometric programming is defined as :

(*a*) $T - (N + 1)$ (*b*) $T + (N + 1)$
(*c*) $T - N$ (*d*) $T > (N + 1)$.

127. Coining is the operation of

(*a*) cold forging (*b*) hot forging
(*c*) cold extrusion (*d*) piercing.

128. Surface roughness of workpiece being machined in USM will .... with increase in abrasive grain diameter.

(*a*) increase (*b*) decrease
(*c*) first increase then become constant (*d*) first decrease then become constant.

129. USM is best suited for .... materials.
(*a*) brittle (*b*) ductile
(*c*) intermediate ductile (*d*) all of these.

130. Increase in back rake angle would affect the surface finish as follows :
(*a*) Improve (*b*) Deteriorate
(*c*) Unchanged (*d*) All of these.

131. Continuous chips will be formed when machining speed is
(*a*) high (*b*) low
(*c*) medium (*d*) all of these.

132. A .... is defined as the availability of one machine for one hour.
(*a*) man-hour (*b*) machine-hour
(*c*) manufacturing time (*d*) production rate.

133. .... defined as the planning of where and by whom the work will be done.
(*a*) Loading and scheduling (*b*) Routing
(*c*) Dispatching (*d*) Follow-up.

134. Production control refers to
(*a*) evaluating the quality of the outgoing product
(*b*) analysis of information and data obtained from field
(*c*) feedback to the production process
(*d*) all of the above.

135. Use of statistical techniques to industrial products is helpful in
(*a*) maintaining quality standards (*b*) improving quality standards
(*c*) both (*a*) and (*b*) (*d*) gaining profits for the management.

136. The objective of the inspection is to
(*a*) improve the quality (*b*) reduce the production cost
(*c*) increase production (*d*) to know the skill of operator.

137. The leader of the synectic group
(*a*) contribute the ideas (*b*) does not contribute the ideas
(*c*) ensures the group functions properly (*d*) both (*a*) and (*c*).

138. The promising idea suggested by the synectic group of experts is
(*a*) developed by the leader later on
(*b*) developed by the group upto the point where the prototype can be made
(*c*) developed by the designer
(*d*) none of the above.

139. The form concept in aesthetics involves the
(*a*) overall visual appearance of an object
(*b*) mechanical operation of the object
(*c*) harmonious combination of parts
(*d*) none of the above.

140. The important aspects of industrial design are :
(*a*) Ethics and Aesthetics
(*b*) Ethics, Economics, Ergonomics and Aesthetics
(*c*) Economics and Ergonomics
(*d*) Aesthetics.

141. Production system is a :
(*a*) Open loop system (*b*) Closed loop system
(*c*) Any of these (*d*) None of these.

142. Transformation process consists of :
(*a*) Plant and machinery (*b*) Labourers
(*c*) Auxillary services (*d*) All of the above.

143. Any new product is a result of :
(*a*) Customer's need (*b*) Market trend
(*c*) More profits concept (*d*) All of these.

144. Machine used to produce channels of I-section, rail section etc. is called ....
(*a*) casting machine (*b*) rolling machine
(*c*) forging plant (*d*) extrusion mill.

145. In a four high rolling mill, diameter of the bigger roller in comparison to diameter of working roller is
(*a*) smaller (*b*) larger
(*c*) same (*d*) no such criteria

146. LASER is produced by :
(*a*) Graphite (*b*) Ruby
(*c*) Diamond (*d*) Aluminium.

147. A 50 tonne press implies that
(*a*) weight of the press is 50 tonnes
(*b*) it can exert pressure upto 50 tonnes
(*c*) it can handle work weighing upto 50 tonnes
(*d*) none of the above.

148. Which of the following waves are used in USM?
(*a*) Shear waves (*b*) Longitudinal waves
(*c*) Either of the above (*d*) None of the above.

149. Longitudinal waves are preferred in USM because
(*a*) they are easily generated
(*b*) they can be propagated in solid, liquid and gases
(*c*) they can travel at a high velocity
(*d*) all of the above.

150. .... is the time during each cycle of the operation that the machine is working or the tools are cutting.
(*a*) Set-up time (*b*) Man time
(*c*) Machine time (*d*) Down time.

151. Stretch forming is the process of

(*a*) cold rolling (*b*) cold drawing

(*c*) forging (*d*) extrusion.

152. Flange wrinkling is the defect found in

(*a*) deep drawing (*b*) blanking

(*c*) spinning (*d*) bending.

153. Accuracy of shell moulding is of the order of :

(*a*) 0.1 mm/mm (*b*) 0.001 mm/mm

(*c*) 0.003 to 0.005 mm/mm (*d*) none of the above.

154. For the steel castings, the following type of sand is better :

(*a*) Coarser grain (*b*) Medium grain

(*c*) Fine grain (*d*) None of the above.

155. True centrifugal casting is used to

(*a*) cast symmetrical objects

(*b*) cast unsymmetrical objects

(*c*) obtain high density and pure castings

(*d*) none of the above.

156. .... is the number of down time hours during which one or more technicians actually work on a system to restore it to operable condition.

(*a*) Active repair time (*b*) Logistic time

(*c*) Administrative time (*d*) Man-hours.

157. .... is the number of down time hours consumed in awaiting parts or units needed to effect a repair.

(*a*) Active repair time (*b*) Logistic time

(*c*) Administrative time (*d*) Man-hours.

158. Ignorance of ergonomics by designer and other decision makers can result in a poor fit between ....

(*a*) user and equipment (*b*) equipment and environment

(*c*) user, equipment and environment (*d*) user and environment.

159. Ignorance of ergonomics by designer and other decision makers is manifested in :

(*a*) The time taken to carry out tasks with the equipment

(*b*) Mistakes being made

(*c*) Feelings of discomfort and dissatisfaction in the user

(*d*) All of the above.

160. In MIG welding, metal is transferred in the form of :

(*a*) weld pool (*b*) molten drops

(*c*) a fine spray of metal (*d*) molecules.

161. Welding of stainless steel is difficult because

(*a*) rust formation takes place (*b*) formation of oxide film

(*c*) either of the above (*d*) none of the above.

162. Some associations of Propositional Calculus which can be viewed as the elements of Boolean Algebra are :

(*a*) Sum can be interpreted as conjunction
(*b*) Product can be interpreted as disjunction
(*c*) Complement can be interpreted as negation
(*d*) All of the above.

163. The .... method involves the calculation of the length of time required to recover the initial capital investment based on zero interest rate.

(*a*) Present worth (*b*) Annual worth
(*c*) Capitalised worth (*d*) Payback period.

164. PFA deals with :

(*a*) Raw materials
(*b*) Machines
(*c*) Sequence of operations in fabrication
(*d*) All of these.

165. Hybrid coding is nothing but

(*a*) monocodes (*b*) polycodes
(*c*) mixed codes (*d*) none of these.

166. The basic objective of quality control in any organisation is to

(*a*) ensure control (*b*) build up customers goodwill
(*c*) achieve optimum cost (*d*) achieve all the above.

167. Three major functions of the production cycle are :

(*a*) Design, manufacturing and inspection
(*b*) Storing, manufacturing and selling
(*c*) Design, manufacturing and storing
(*d*) None of the above.

168. Casting process is preferred having

(*a*) few details (*b*) many details
(*c*) no details (*d*) all of the above.

169. In order to facilitate the withdrawal of pattern

(*a*) draft is provided on pattern
(*b*) withdrawal facilities are provided
(*c*) water is applied on pattern surface
(*d*) all of the above.

170. Cutting and forming operations can be done in a single operation

(*a*) simple die (*b*) compound die
(*c*) combination die (*d*) none of the above.

171. For drawing operation, the best suited press is :

(*a*) Rack and pinion press (*b*) Toggle press
(*c*) Knuckle joint press (*d*) None of the above.

172. Physical aspects of the user-machine interface involves :
(*a*) size and shape
(*b*) colour and texture
(*c*) methods of operation of displays and controls
(*d*) all of the above.

173. Understanding of instructions and other information is .... aspects of the user-machine interface.
(*a*) physical (*b*) cognitive
(*c*) psycological (*d*) workplace design.

174. In arc welding, eyes need to be protected against
(*a*) infra-red and ultraviolet rays (*b*) sparks
(*c*) intense glare (*d*) none of the above.

175. In which type of welding a pool of molten metal is used?
(*a*) Thermit welding (*b*) Electroslag
(*c*) Submerged arc (*d*) All of the above.

176. Group technology results in :
(*a*) less implementation cost (*b*) easy change in product design
(*c*) either of the above (*d*) none of the above.

177. Geometric classification of families is based on :
(*a*) Size
(*b*) Shape
(*c*) Sequence and number of operations
(*d*) (*a*) and (*b*) only.

178. Ergonomics deals with :
(*a*) Economics
(*b*) Cost of product
(*c*) Comfort and safety of a product while in use
(*d*) None of the above.

179. Standardization means :
(*a*) Standard trade mark (*b*) More price
(*c*) More surface finish (*d*) Interchangeability of components.

180. Injection moulding is the ideal method of processing for
(*a*) plastics (*b*) thermosetting plastics
(*c*) thermoplastics (*d*) non-ferrous alloys.

181. The medium necessary for corrosion to take place is :
(*a*) Air (*b*) Moisture
(*c*) Vacuum (*d*) All of these.

182. Brainstorming is a method of accummulating ideas by practising
(*a*) individual approach (*b*) team approach
(*c*) conference technique (*d*) none of the above.

183. Brainstorming allows

(*a*) stimulation of ideas (*b*) criticism of ideas
(*c*) evaluation of ideas (*d*) all of the above.

184. Existing ideas with slight modifications if used for similar applications in problem solving are termed as :

(*a*) Developed ideas (*b*) Adaptive ideas
(*c*) New ideas (*d*) None of the above.

185. The type of approach of problem solving where many experts work together is called :

(*a*) Individual approach (*b*) Team approach
(*c*) Brainstorming (*d*) Survey.

186. Heat generated in metal cutting can be conveniently determined by :

(*a*) Using radiation pyrometer (*b*) Calorimeter set-up
(*c*) Infra-red technique (*d*) Any of the above.

187. Trimming is associated with

(*a*) press work (*b*) forging
(*c*) polishing of metals (*d*) machining.

188. Ductility of a metal with work hardening

(*a*) increases (*b*) decreases
(*c*) unpredictable (*d*) none of the above.

189. .... refers to the process of generation of ideas.

(*a*) Ideation (*b*) Identification
(*c*) Aesthetics (*d*) Modification.

190. .... is a method of stimulating ideas.

(*a*) Checklists (*b*) Brainstorming
(*c*) Problem definition (*d*) Both (*a*) and (*b*).

191. Similar machines are kept at one location in .... type of plant layout.

(*a*) process (*b*) product
(*c*) combination (*d*) all the above.

192. In .... type of plant layout, machines are placed in the sequence in which the product will be manufactured.

(*a*) process (*b*) product
(*c*) combination (*d*) all the above.

193. Cutting speed in machining with HSS tool will be maximum when machining

(*a*) cast iron (*b*) mild steel
(*c*) aluminium (*d*) wrought iron.

194. Strength of a cutting tool depends on the following angle :

(*a*) Lip angle (*b*) Clearance angle
(*c*) Rake angle (*d*) None of these.

195. Spruce in casting refers to
(*a*) riser (*b*) horizontal passage
(*c*) vertical passage (*d*) none of the above.

196. Steel and cast iron pipes are cast by
(*a*) true centrifugal casting (*b*) die casting
(*c*) electroslag casting (*d*) none of the above.

197. In geometric programming, the values of the weighing functions .... in order to optimise the value of the objective function.
(*a*) can be changed (*b*) cannot be changed
(*c*) are calculated (*d*) none of the above.

198. Which of the following governs metal removal rate in electrochemical machining?
(*a*) Faraday's law (*b*) Newton's law
(*c*) Fleming's rule (*d*) Einstein rule.

199. Which is false statement about plasma arc machining?
(*a*) Metal properties remain same even without shielding.
(*b*) Simple work supports required.
(*c*) It is almost equally effective on any metal irrespective of hardness.
(*d*) Metal removal rate can be increased by increasing the gas flow rate.

200. In EDM process, the workpiece is connected to
(*a*) negative (*b*) positive
(*c*) earth (*d*) none of the above.

201. In ECM, metal is removed by ....
(*a*) highly accelerated electron flow owing to ionization of the fluid medium.
(*b*) anodic dissolution.
(*c*) etchant solution.
(*d*) stimulated emission.

202. Tooling cost is .... for ECM process compared to that of the EDM process.
(*a*) very high (*b*) very low
(*c*) medium (*d*) practically nil.

203. Cold working
(*a*) decreases the fatigue strength (*b*) increases the fatigue strength
(*c*) has no influence on fatigue strength (*d*) none of the above.

204. Which of the following is a gear finishing operation?
(*a*) Sharing or burnishing (*b*) Shaping
(*c*) Hobbing (*d*) None of the above.

205. In ECM, best surface finish is obtained
(*a*) with low current density (*b*) with high current density
(*c*) with slow rate of metal removal (*d*) with high rate of metal removal.

206. Electrolyte used in ECM process is
(*a*) brine solution (*b*) kerosene
(*c*) water (*d*) air.

207. Projection welding is
(*a*) multispot welding process (*b*) a sort of seam welding
(*c*) used to make cantilevers (*d*) none of these.

208. Welding process in which two pieces to be joined are overlapped and placed between two pointed electrodes is known as :
(*a*) Projection welding (*b*) Seam welding
(*c*) Spot welding (*d*) Resistance welding

209. The portion of tool on which cutting edge is formed is called :
(*a*) Flank (*b*) Shank
(*c*) Face (*d*) Nose.

210. A reamer is used to correct
(*a*) size and position of drilled hole (*b*) size and roundness of hole
(*c*) finish and size of a drilled hole (*d*) none of the above.

211. Quality is the responsibility of
(*a*) production personnel (*b*) quality control personnel
(*c*) nobody (*d*) everybody.

212. Group technology consists of
(*a*) grouping of workshops (*b*) grouping of the labourers
(*c*) grouping of executives (*d*) grouping of machines.

213. Calculation of the metal cutting time depends on the correct selection of values for the
(*a*) cutting speed (*b*) feed rate
(*c*) depth of cut (*d*) all of the above.

214. Manufacturing costs comprises of
(*a*) material cost (*b*) overhead cost
(*c*) depreciation (*d*) all of these.

215. Overhead expenses include
(*a*) fringe benefits of company executive
(*b*) depreciation
(*c*) taxes
(*d*) all the above.

216. Cores are used to
(*a*) straighten moulding sand (*b*) make desired recess in castings
(*c*) remove pattern easily (*d*) none of the above.

217. Mechanical properties of the metal improve in hot working due to
(*a*) refinement of grain size (*b*) recrystallisation
(*c*) recovery of grains (*d*) all of the above.

218. The most important properties for a tool material employed for high speed machining are :
(*a*) Toughness and impact resistance

(*b*) Red hardness, wear resistance and toughness
(*c*) Red hardness, and impact resistance
(*d*) Red hardness and wear resistance.

219. Average cutting speed in machining cost iron by a single-point cutting tool of H.S.S. is
(*a*) 22 m/mt (*b*) 10 m/mt
(*c*) 18 m/mt (*d*) 30 m/mt

220. Chips with built-up edge can be expected when machining
(*a*) brittle material (*b*) ductile material
(*c*) hard material (*d*) none of the above.

221. Crater wear takes place is a single-point cutting tool at
(*a*) side rake (*b*) tip
(*c*) face (*d*) flank.

222. Tool signature consists of
(*a*) 2 elements (*b*) 3 elements
(*c*) 4 elements (*d*) none of these.

223. In metal cutting at speed above 20 m/mm, maximum heat is carried by :
(*a*) tool (*b*) chip
(*c*) work (*d*) none of the above.

224. The main function of the cutting fluid is to
(*a*) cool the tool and workpiece (*b*) provide lubrication
(*c*) improve surface finish (*d*) all of the above.

225. Tool signature is
(*a*) a numerical method of identification of tool
(*b*) the plan of tool
(*c*) there is nothing like tool signature
(*d*) none of the above.

226. .... is a method of optimisation of non-linear objective functions.
(*a*) Geometric programming (*b*) Linear programming
(*c*) Dynamic programming (*d*) None of the above.

227. In .... search method, a pair of trial points near the center of the allowable range of values of the variable is evaluated.
(*a*) uniform (*b*) sequential
(*c*) golden section (*d*) sequential simplex.

228. Custom, habit and tradition come in the way of
(*a*) creativity (*b*) ideonomics
(*c*) innovations (*d*) none of the above.

229. One of the steps in designing by creative persons is incubation. This means
(*a*) relief or relaxation away from problem (*b*) test and completion of the details
(*c*) collection of pertinent information (*d*) none of the above.

230. Ornaments are cast by

(*a*) pressed or corthias casting (*b*) centrifugal casting
(*c*) gravity casting (*d*) none of the above.

231. Ornamental objects, statues, toys etc. are casted by

(*a*) slush casting (*b*) pressed casting
(*c*) die casting (*d*) none of the above.

232. Design is motivated by :

(*a*) need (*b*) curiosity
(*c*) advancement (*d*) none of the above.

233. The following are the stages in any design process :

(*a*) To identify requirement (*b*) Specification
(*c*) Study of alternatives (*d*) All of the above.

234. For achieving good standard of performance in a system the designer has to incorporate the following factors :

(*a*) Reliability level (*b*) Safety
(*c*) Ease of maintenance (*d*) All of the above.

235. Transferring moulding is also known as :

(*a*) Flaskless moulding machine (*b*) Automatic moulding
(*c*) Bench moulding (*d*) Investment casting.

236. Capital recovery factor, CRF is related to the sinking fund factor, SFF by the relation :

(*a*) CRF = SFF + 1 (*b*) CRF = SFF – 1
(*c*) CRF = SFF (*d*) SFF = CRF + 1

237. The .... method uses the equivalent present value of all current and future cash flows to evaluate the different alternatives.

(*a*) annual worth (*b*) future worth
(*c*) payback period (*d*) present worth.

238. Hardest manufactured cutting tool material is :

(*a*) Diamond (*b*) H.S.S.
(*c*) Cemented carbide (*d*) Carbon steel.

239. Type of chip produced when cutting a ductile material is :

(*a*) Continuous (*b*) Discontinuous
(*c*) With built-up edge (*d*) Any of the above.

240. Point of a twist drill is thinned in order to

(*a*) decrease the rake angle (*b*) increase the rake angle
(*c*) reduce axial feed pressure (*d*) reduce hole diameter.

241. Hardness of carbon tool steels is increased when alloyed with

(*a*) tungsten (*b*) chromium and vanadium
(*c*) silicon (*d*) mangenese.

242. High speed steel tool material contain carbon as
(*a*) 0.6 – 1.0% (*b*) 2 – 4%
(*c*) 4 – 6% (*d*) 10 – 12%

243. Designing by Scientific Logic and Propositional Calculus helps in solving the problem by providing
(*a*) a logical approach (*b*) an arbitrary choice
(*c*) truth tables and Boolean algebra (*d*) both (*a*) and (*c*).

244. The interpretation of axioms in Scientific Logic are
(*a*) same as that of ordinary algebra symbols
(*b*) different as that of ordinary algebra symbols
(*c*) can be done with the help of Venn diagram
(*d*) both (*a*) and (*c*).

245. Hot tears in castings are caused by
(*a*) excessive mould hardness (*b*) high dry and hot strength of mould
(*c*) either of (*a*) or (*b*) (*d*) none of these.

246. Rough surface of casting may result from :
(*a*) High permeability of sand (*b*) Large grain size
(*c*) Soft ramming (*d*) Any of these.

247. Chaplets are
(*a*) core binders (*b*) core supports
(*c*) core projections (*d*) mould seats to support cores.

248. A cutting tool angle having tool signatures as 10, 10, 6, 6, 8, 8, 2 will have back rake angle as :
(*a*) 10 (*b*) 6
(*c*) 8 (*d*) 2.

249. Carbide tool wears out faster at
(*a*) slow speed (*b*) medium speed
(*c*) fast speed (*d*) very fast speed.

250. Carbide tips are fixed to the shanks of cutting tools by
(*a*) forging (*b*) sintering
(*c*) welding (*d*) brazing.

251. A product which possesses more than the allowable number of defects is called as
(*a*) defective (*b*) defect
(*c*) number of defectives (*d*) reject.

252. The control charts, p-chart and C-chart, are used for
(*a*) variables (*b*) attributes
(*c*) variables and attributes (*d*) large samples only.

253. If the lower control limit is negative then LCL is taken as
(*a*) positive (*b*) negative
(*c*) zero (*d*) equal to UCL.

254. In oblique cutting system, the chip thickness is

(*a*) maximum at middle (*b*) maximum at sides

(*c*) minimum at middle (*d*) uniform throughout.

255. Negative rakes are used for

(*a*) heavy loads (*b*) harder materials

(*c*) carbide tools (*d*) all of the above.

256. Purpose of side rake is to

(*a*) shear the metal (*b*) control chip flow

(*c*) break chips (*d*) none of the above.

257. Maximum cutting angles are used for machining

(*a*) mild steel (*b*) cast iron

(*c*) aluminium alloys (*d*) nickel alloys.

258. A cupola one metre in diameter and four metres in height will melt in one hour about

(*a*) 0.5 tonnes of iron (*b*) 2 tonnes of iron

(*c*) 5 tonnes of iron (*d*) 10 tonnes of iron.

259. Important property of the material to be deformed is :

(*a*) Elasticity (*b*) Plasticity

(*c*) Ductility (*d*) Toughness.

260. An important product manufactured by rolling is :

(*a*) I-section (*b*) Tubes

(*c*) Metal rolls (*d*) Rollers.

261. Which of the following materials can be forged ?

(*a*) Wrought iron (*b*) Cast iron

(*c*) Mild steel (*d*) H.S.S.

262. Seam welding is

(*a*) force welding (*b*) continuous spot welding process

(*c*) used to form mesh (*d*) none of the above.

263. The brazing metals and alloy commonly used are

(*a*) silver alloys (*b*) aluminium alloys

(*c*) copper alloys (*d*) all of the above.

264. In thermit welding, the iron oxide and aluminium oxide are mixed in the proportion of :

(*a*) 3 : 1 (*b*) 1 : 3

(*c*) 1 : 1 (*d*) none of the above.

265. Average cutting speed in machining cast iron by a single point cutting tool of H.S.S. is :

(*a*) 6 m/min (*b*) 22 m/min

(*c*) 33 m/min (*d*) 44 m/min.

266. Front rake required to machine brass by H.S.S. tool is :

(*a*) 15 (*b*) 10

(*c*) 5 (*d*) 0.

267. Chaplets are provided to

(*a*) reduce core sag

(*b*) support heavy cores

(*c*) compensate for inadequate core seats

(*d*) all of the above.

268. Chaplets are made of

(*a*) core sand (*b*) organic matter

(*c*) wood (*d*) metal.

269. Cross-section of a sprue is

(*a*) square (*b*) circular

(*c*) rectangular (*d*) any of the above.

270. In bending operation, the metal takes shape of

(*a*) could take any shape (*b*) punch

(*c*) die (*d*) none of the above.

271. Average cutting speed in machining mild-steel by single point tool of H.S.S. is

(*a*) 20 m/min (*b*) 30 m/min

(*c*) 40 m/min (*d*) 50 m/min.

272. AJM is used for

(*a*) removing flash and parting lines from injection moulded parts

(*b*) deburring and polishing plastic, nylon and teflon components

(*c*) cutting thin sectioned fragile components made of glass, refractories, ceramics, mica etc.

(*d*) all of the above.

273. AJM is used for

(*a*) ductile materials only (*b*) brittle materials only

(*c*) plastics only (*d*) none of these.

274. Ultrasonic machining is based on

(*a*) vibratory waves of high frequency (*b*) uniform grinding

(*c*) uniform machining (*d*) uniform heating.

275. Frequency used in ultrasonic machining is

(*a*) within audible range (*b*) more than audible range

(*c*) any value of frequency (*d*) none of these.

276. The feedback on quality is done by

(*a*) quality analysis (*b*) quality audits

(*c*) quality appraising (*d*) quality planning.

277. The sub-function which establishes the basic framework of the entire quality control system for the company is

(*a*) quality control engineering
(*b*) process control engineering
(*c*) quality information equipment engineering
(*d*) any of these.

278. The maximum allowable number of defectives in the sample of a given lot to accept is called :

(*a*) AQL (*b*) Rejection number
(*c*) Acceptance number (*d*) Sample size.

279. The maximum percent defective that the consumer indicates will be accepted is called :

(*a*) AQL (*b*) AOQL
(*c*) LTPD (*d*) LT.

280. The method of cost estimation used by an employee based on his acquaintance with similar products is termed as

(*a*) experience (*b*) engineering Analysis
(*c*) statistical method (*d*) none of the above.

281. In .... method the separate elements of work are identified in great detail.

(*a*) experience (*b*) engineering Analysis
(*c*) statistical (*d*) none of the above.

282. Which of the following is a medium grade grinding wheel with open structure?

(*a*) A 46-Q6-V10 (*b*) A 46-G4-V10
(*c*) A 46-K10-V10 (*d*) A 46-R121-V10.

283. In most high speed milling cutters, positive radial rake angle is

(*a*) 10°–15° (*b*) 15°–20°
(*c*) 20°–25° (*d*) 25°–30°.

284. .... is the unavoidable time lost by the operator.

(*a*) Set-up time (*b*) Man time
(*c*) Machine time (*d*) Down time.

285. .... is the time which elapses between picking up a part to load on the machine and depositing it after unloading from the machine.

(*a*) Floor to floor time (*b*) Man time
(*c*) Machine time (*d*) Down time.

286. If the feed is stopped and the cutter continues to rotate, the cutter will .... in the metal.

(*a*) feed down (*b*) cut microsize chip
(*c*) vibrate (*d*) create heat.

287. The build-up edge with chip is formed when ....

(*a*) feed is coarse (*b*) material is ductile
(*c*) friction at chip tool interface is high (*d*) cutting speed is low.

288. Various reasons for engineering changes can be :
(*a*) Management decision
(*b*) Need to improve reliability of product
(*c*) To incorporate better features of competitor
(*d*) All the above.

289. It is essential to work out the value of change versus
(*a*) the service of the product (*b*) the cost of incorporating the same
(*c*) the profit (*d*) none of the above.

290. The proposal for effecting the alteration has to be prepared after analysing :
(*a*) Cost (*b*) Value and cost of alteration
(*c*) Extent, cost and value of alteration (*d*) Value.

291. Lathe spindle has got
(*a*) taper threads (*b*) no threads
(*c*) external threads (*d*) none of the above.

292. Angular clearance provided on dies is of the order of
(*a*) ½ to 1° (*b*) 3 to 5°
(*c*) 2 to 3° (*d*) none of the above.

293. Amount of coal dust added to moulding sand depends on
(*a*) shape of the casting (*b*) thickness of casting
(*c*) temperature of pouring (*d*) none of the above.

294. Addition of saw dust to moulding sand increase its
(*a*) gas permeability (*b*) refractoriness
(*c*) cohesiveness (*d*) all of the above.

295. The characteristic that enables one material to cut other is its relative
(*a*) toughness (*b*) hardness
(*c*) ductility (*d*) strength.

296. Reliability prediction is
(*a*) for infinite period of time (*b*) for specified period of time
(*c*) independent of time period (*d*) none of the above.

297. Complexity of construction of a product .... the reliability of the product.
(*a*) affects (*b*) does not affect
(*c*) increases (*d*) none of the above.

298. Unreliability is
(*a*) reciprocal of reliability (*b*) 1 – reliability
(*c*) independent of reliability (*d*) 1 + reliability.

299. Utility scale is .... a proportional scale.
(*a*) always (*b*) not
(*c*) multiple of (*d*) none of the above.

300. In many cases, the utility curves can be approximated by a .... curve.
(*a*) parabola (*b*) straight line
(*c*) logarithmic (*d*) hyperbola.

301. .... is used to satisfy the test of indifference on the various quality dimensions.

(*a*) Weighing factors
(*b*) A constant between 0 and 10
(*c*) Any number
(*d*) All the above.

302. The correct problem statement is which defines

(*a*) the basic requirements to be met
(*b*) all the parameters and details of the problem
(*c*) the solution of the problem
(*d*) none of the above.

303. The common situation where inadequate problem formulation retards progress is/are :

(*a*) Failure to recognise that a problem exists
(*b*) Incorrect identification of the real problem
(*c*) Both (*a*) and (*b*)
(*d*) None of the above.

304. Traditional tools and machines were

(*a*) relatively simple
(*b*) made by the user
(*c*) made in small numbers
(*d*) all the above.

305. Present day tools and machines are

(*a*) increasingly complex
(*b*) made in large numbers
(*c*) made by a manufacturer
(*d*) all the above.

306. In gas welding the highest temperature is obtained with a

(*a*) neutral flame
(*b*) oxidising flame
(*c*) carburising flame
(*d*) any of these.

307. .... is a measure of the net worth, or value of a system to the user.

(*a*) Maintainability
(*b*) Availability
(*c*) System effectiveness
(*d*) Performance capability.

308. Availability is a function of ....

(*a*) reliability
(*b*) maintainability
(*c*) both (*a*) and (*b*)
(*d*) system effectiveness.

309. Maintenance action can be classified as :

(*a*) Preparation and malfunction verification
(*b*) Fault location and part procurement
(*c*) Repair and final malfunction test
(*d*) All the above.

310. The factors which limit the accuracy of any maintenance time predictions are:

(*a*) Weather
(*b*) Skill of maintenance crew
(*c*) Familiarity with the system
(*d*) All the above.

311. What is the principles of Water Jet Machining (WJM) ?

(*a*) A jet of water is directed on the surface at a high velocity.
(*b*) Surface is dipped in the water
(*c*) Air and water mix jet is used
(*d*) Any of the above.

312. In electro-discharge machining (EDM), metal removal takes place as
(*a*) erosion of metal (*b*) dissolution of metal
(*c*) chemical reaction of metal (*d*) none of these.

313. Process inspection is carried out during
(*a*) surface hardening of MS plate (*b*) thread cutting on a lathe machine
(*c*) manufacture of the bottles (*d*) surface grinding.

314. Air gauge is a
(*a*) pneumatic comparator (*b*) mechanical comparator
(*c*) electrical comparator (*d*) electronic comparator.

315. The basic objective of quality control in any organisation is to
(*a*) achieve optimum cost (*b*) ensure control
(*c*) build up customer goodwill (*d*) all of the above.

316. The quality maintenance of patterns and tools comes under
(*a*) prevention cost (*b*) appraisal cost
(*c*) failure cost (*d*) total cost of quality control.

317. Most commonly used flame in gas welding is
(*a*) neutral flame (*b*) oxidising flame
(*c*) carburising flame (*d*) mixture of the three.

318. Maximum flame temperature occurs at
(*a*) the tip of the flame (*b*) inner cone
(*c*) next to inner cone (*d*) at the outer cone.

319. Slurry is fed in USM by
(*a*) manual system (*b*) by a high power pump
(*c*) any of the above (*d*) none of the above.

320. Abrasive jet machining uses
(*a*) a jet of fine grained abrasive particles mixed with air or some other carrier gas at high pressure
(*b*) a jet of abrasive particles suspended in water
(*c*) a jet of suspended particles suspended in oil
(*d*) none of the above.

321. System cost includes the total amount for
(*a*) development (*b*) production
(*c*) service-life support (*d*) all the above.

322. Preventive maintenance scheduling is primarily for the improvement of
(*a*) maintenance effectiveness (*b*) system effectiveness
(*c*) reliability (*d*) none of the above.

323. Need for product modification is recognised by the
(*a*) designer (*b*) customer
(*c*) manufacturer (*d*) any one of the above.

324. Need which deals with what the design should do when it is completed and in operation is
(*a*) performance need (*b*) time need
(*c*) cost need (*d*) none of the above.

325. Qualifying design concept means
(*a*) validating the design concept
(*b*) selection of any design concept
(*c*) fixing minimum requirements for the design
(*d*) none of the above.

326. Testing is a tool to validate
(*a*) the product manufacture (*b*) standard marking
(*c*) the design concept (*d*) none of the above.

327. Some of the methods for improving reliability are :
(*a*) Redundancy and standby arrangement
(*b*) Simplicity and Specificity
(*c*) Durability
(*d*) All the above.

328. .... identifies potential causes of failure, rates them in terms of criticality.
(*a*) Hazard analysis (*b*) Assessing design reliability
(*c*) Inspection (*d*) None of the above.

329. Presence of sulphur in cast iron
(*a*) retards fluidity (*b*) promotes brittleness
(*c*) promotes oxidation (*d*) all of the above.

330. Value analysis has as its objective of
(*a*) cheapening of products or services (*b*) diminishing essential qualities
(*c*) decreasing safety in products (*d*) none of the above.

331. Definition of value analysis involves :
(*a*) use value (*b*) esteem value
(*c*) cost value (*d*) both (*a*) and (*b*).

332. Depreciation allowances are provided by a company to account for
(*a*) wear (*b*) deterioration
(*c*) obsolescence (*d*) all the above.

333. Benefit-cost analysis is commonly used for evaluating
(*a*) public sector projects (*b*) private sector projects
(*c*) all types of projects (*d*) small projects.

334. The three basic aspects involved in any quality control programme are :
(*a*) Planning, engineering and inspection
(*b*) Engineering, statistical and managerial
(*c*) Statistical, inspection and planning
(*d*) Engineering, managerial and planning.

335. The concept of prevention and control come under
(*a*) planning (*b*) engineering
(*c*) statistical (*d*) none of the above.

336. Carburising flame as compared to oxidising flame is
(*a*) more luminuous (*b*) less luminuous
(*c*) equal luminuous (*d*) none of the above.

337. Temperature of inner luminuous core of neutral flame is of the order of
(*a*) 3500°C (*b*) 2500°C
(*c*) 1500°C (*d*) 5900°C.

338. In submerged arc welding
(*a*) there is no arc in actual
(*b*) arc is maintained under a blanket of flux
(*c*) arc is submerged in molten metal bath
(*d*) none of the above.

339. Temperature of oxy-hydrogen flame as compared to oxy-acetylene flame is
(*a*) less (*b*) same
(*c*) more (*d*) any value is possible.

340. The factors influencing system performance are :
(*a*) Equipment of new design
(*b*) Interrelationships among various system properties
(*c*) Both (*a*) and (*b*)
(*d*) None of the above.

341. X-Rays are used in
(*a*) radiography (*b*) thermal methods
(*c*) magnetic testing (*d*) ultrasonic testing.

342. Sine bar is used for measuring
(*a*) length (*b*) area
(*c*) height (*d*) angle.

343. Feeler gauge is used for measuring
(*a*) thickness of small gap (*b*) length of the grooves
(*c*) pitch of the thread (*d*) angle of countersunk.

344. Concept screening is done to
(*a*) avoid wrong selection of concept (*b*) find better solutions
(*c*) avoid some specifications (*d*) none of these.

345. Brainstorming is a method to foster
(*a*) productivity (*b*) creativity
(*c*) both (*d*) none of these.

346. Slurry used in USM is
(*a*) water based (*b*) mercury based
(*c*) alcohol based (*d*) alkaline only.

347. Ultrasonics in medical field is used for

(*a*) operations (*b*) diagnosis
(*c*) not used in medical sciences (*d*) both (*a*) and (*b*).

348. Distortion in welding occurs due to

(*a*) use of high voltage (*b*) improper clamping methods
(*c*) oxidation of weld pool (*d*) use of high current.

349. Oxygen to acetylene ratio in case of neutral flame is :

(*a*) 0.8 : 1.0 (*b*) 1 : 1
(*c*) 2 : 1 (*d*) 4 : 1.

350. Striking voltage as compared to voltage during arc welding is

(*a*) same (*b*) more
(*c*) less (*d*) unpredictable.

351. Advantages of laser beam machining are :

(*a*) There is no contact between tool an workpiece.
(*b*) Laser beam can be sent to longer distances without diffraction.
(*c*) Heat treated and magnetic particles can be welded without losing their properties.
(*d*) None of the above.
(*e*) All of the above.

352. Which of the following is high energy rate forming?

(*a*) Explosive fabrication (*b*) Forging
(*c*) Upsetting (*d*) Rolling.

353. Which of the following materials can be machined by USM ?

(*a*) Ductile material (*b*) Brittle material
(*c*) Both (*a*) and (*b*) (*d*) None of these.

354. Which is the function of the tool cone ?

(*a*) It focuses the mechanical energy produced by the transducer and imparts this to the workpiece in such a way that energy utilisation is optimum.
(*b*) It rotates and makes hole in the metal.
(*c*) It is preferred when conical holes are to be made.
(*d*) None of the above.

355. Carburising flame has

(*a*) 1 zone (*b*) 2 zones
(*c*) 3 zones (*d*) 4 zones.

356. Acetylene gas is generated from

(*a*) calcium carbide (*b*) carbon
(*c*) calcium (*d*) calcium carbonate.

357. Electrode gets consumed in the following welding process :

(*a*) Gas welding (*b*) Resistance welding
(*c*) Thermit welding (*d*) Arc welding
(*e*) TIG welding.

358. Two stainless steel foils of thickness 0.1 mm thickness are to be joined. Which process is best suited ?

(*a*) Plasma arc welding (*b*) Gas welding
(*c*) TIG welding (*d*) MIG welding.

359. Are length in arc welding should be equal to :

(*a*) half the diameter of the electrode (*b*) equal to electrode diameter
(*c*) 2.5 times the electrode diameter (*d*) any of the above.

360. The brazing metals and alloys commonly used are :

(*a*) Copper and copper alloys (*b*) Silver alloys
(*c*) Aluminium alloys (*d*) All of the above.

361. Forge welding is best suited for

(*a*) stainless steel (*b*) wrought iron
(*c*) cast iron (*d*) all of the above.

362. LASER welding finds widest applications in :

(*a*) heavy industry (*b*) structural work
(*c*) electronic industry (*d*) all of these.

363. Cross wire welding is

(*a*) continuous spot welding process
(*b*) used to form mesh
(*c*) used where more strength is required
(*d*) none of the above.

364. Casting process is preferred for parts having

(*a*) a few details (*b*) no details
(*c*) many details (*d*) none of the above.

365. Core are used to :

(*a*) remove pattern easily (*b*) support loose pieces
(*c*) make desired recess in casting (*d*) none of the above.

366. Any manufactured part possessing one or more defects is said to have(be)

(*a*) defects (*b*) fraction defective
(*c*) percent defective (*d*) defective.

367. Control charts used for defects are :

(*a*) *p*-chart (*b*) *pn*-chart
(*c*) *c*-chart (*d*) *p*- and *c*-chart.

368. In arc welding, temperature is of the order of

(*a*) 2500°C (*b*) 3500°C
(*c*) 5500°C (*d*) 10000°C.

369. For long arch lengths, voltage and current respectively will be

(*a*) High, low (*b*) High, high
(*c*) Low, low (*d*) No criteria like that.

370. 'Misrun' is a casting defect which occurs when

(*a*) the pouring temperature is very high
(*b*) gases have been absorbed by the liquid metal
(*c*) sufficient superheat has not been provided to the liquid metal
(*d*) the alignment is improper.

371. In sand moulding the bottom most part of flask is called

(*a*) drug (*b*) flash bottom
(*c*) cope (*d*) none of the above.

372. Decision under uncertainly means where each action results in

(*a*) some outcomes
(*b*) known and well-defined outcome
(*c*) unpredictable outcomes
(*d*) predictable outcomes with probability values less than one.

373. Decision matrix mode is used when the decision situations happen

(*a*) at the same time (*b*) in a sequential fashion
(*c*) both (*a*) and (*b*) (*d*) none of the above.

374. Decision tree model is used when the decision situations happen

(*a*) at the same time (*b*) in a sequential fashion
(*c*) both (*a*) and (*b*) (*d*) none of the above.

375. The standard deviation of fraction defective varies

(*a*) directly with the square root of the sample size
(*b*) directly with the square of the sample size
(*c*) inversely with the square of the sample size
(*d*) inversely with the squareroot of the sample size.

376. The modern machining process working on Faraday's law of electrolyte is known as

(*a*) EDM (*b*) EBM
(*c*) ECM (*d*) LBM.

377. ECM stands for :

(*a*) Electron changing motion (*b*) Electric charged machining
(*c*) Electrochemical machining (*d*) Electron chemical method

378. USM stands for :

(*a*) Ultimate speed machining (*b*) Ultrasonic method
(*c*) Ultrasonic machine (*d*) Ultrasonic machining.

379. Following gas is used in Tungsten inert gas welding :

(*a*) Hydrogen and oxygen (*b*) Carbon dioxide and hydrogen
(*c*) Argon and neon (*d*) Helium and neon
(*e*) Argon and helium.

380. T-joint weld is used

(*a*) where longitudinal shear is present (*b*) to join two pieces perpendicularly
(*c*) to join two pieces as in riveting (*d*) none of the above.

381. The percent of defectives in a lot that can he tolerated in only a specified portion of lot is named

(*a*) AOQ (*b*) AQL
(*c*) LTPD (*d*) AOQL.

382. OC curves are used for the selection lots by

(*a*) variables (*b*) attributes
(*c*) variables and attributes (*d*) random.

383. The fractional producer's risk varies from :

(*a*) 1 to 10 (*b*) 0.1 to 10
(*c*) 0.01 to 0.10 (*d*) 1 to 5.

384. The overall utility of a product is the .... of utilities of each of the quality dimensions.

(*a*) sum (*b*) multiplication
(*c*) subtraction (*d*) division.

385. .... is that property of the utility scale where the total utility is maximised irrespective of different quality dimensions.

(*a*) Difference (*b*) Indifference
(*c*) Overall utility (*d*) None of the above.

386. Advantage of floor inspection is that

(*a*) the defects of job are known before it is completed
(*b*) the production errors are detected at the start itself
(*c*) the production control becomes easy
(*d*) it involves more material handling.

387. Material handling is more in case of

(*a*) floor inspection (*b*) first piece inspection
(*c*) centralised inspection (*d*) patrol inspection.

388. Update of product involves

(*a*) addition of capacity (*b*) improvement of perfomance
(*c*) both (*a*) and (*b*) (*d*) none of the above.

389. The technique which is concerned with procedures for incorporation of engineering changes is termed as

(*a*) Alter-technics (*b*) Alterations
(*c*) Problem identification (*d*) Aesthetics.

390. If the budget of time and money is limited then whether or not, the design is realisable becomes

(*a*) evident (*b*) uncertain
(*c*) both (*a*) and (*b*) (*d*) sure.

391. The project of achieving a design that can be realised physically depends on

(*a*) time (*b*) money
(*c*) evidence (*d*) all the above.

392. A designer should try to determine which of the design concepts are physically realisable within the given ....

(*a*) budgets of time and money (*b*) time
(*c*) money (*d*) budgets of expertise.

393. The real worth of a design in relation to its cost can be measured in terms of its ....

(*a*) overall perfomance rating (*b*) physical realisability
(*c*) cost (*d*) all the above.

394. Seam welding is

(*a*) multispot welding process (*b*) continuous spot welding process
(*c*) used for welding cylindrical objects (*d*) any of these.

395. Preheating is essential in welding

(*a*) cast iron (*b*) stainless steel
(*d*) copper (*d*) aluminium.

396. As our belief (or confidence) in the physical realisability of the concept is strengthened, we are more inclined to .... it.

(*a*) reject (*b*) discuss
(*c*) select (*d*) all the above.

397. Confidence level on a problem scale is measured from

(*a*) 0 to 10 (*b*) 0 to 1
(*c*) 0 to 100 (*d*) none of the above.

398. Group technology consists of

(*a*) grouping of workshops (*b*) grouping of labourers
(*c*) grouping of executives (*d*) grouping of machines.

399. Noise can be reduced by applying

(*a*) sound deadening material (*b*) partition of metallic chamber
(*c*) different environment (*d*) none of the above.

400. A lay.. of dirt could .... heat radiation.

(*a*) increase (*b*) decrease
(*c*) cause same (*d*) none of the above.

401. Most of the organisation has .... for financing projects.

(*a*) infinite funds (*b*) limited funds
(*c*) no funds (*d*) none of the above.

402. The present day product has to compete in fiercely competitive market, therefore it should have

(*a*) usability (*b*) engineering excellence
(*b*) aesthetics (*d*) all the above.

403. The designer of tools and machines must now cater for a market containing extremes of

(*a*) age (*b*) health
(*c*) physical and mental ability (*d*) all the above.

404. A system consists of
(*a*) input variables (*b*) output variables
(*c*) transformation process (*d*) all of these.

405. Open loop system consists of
(*a*) feed back (*b*) comparison of input and output
(*c*) either of the above (*d*) none of the above.

406. The physical realisability of a design concept can be measured in terms of
(*a*) subjective probability (*b*) a ratio
(*c*) a number (*d*) objective probability.

407. Tree structure of design shows different
(*a*) levels of sub-problems (*b*) details of design
(*c*) probabilities of design (*d*) all of these.

408. .... is unavoidable time lost by the operator.
(*a*) Down time (*b*) Set up time
(*c*) Man time (*d*) Machine time.

409. Tractability is the more important selection criteria during the .... of a design.
(*a*) earlier phases (*b*) later stages
(*c*) process (*d*) none of the above.

410. Cost of producing a realisable design is the selection criteria during the .... of a design.
(*a*) earlier phases (*b*) later stages
(*c*) process (*d*) none of the above.

411. Severity of the corrosion for two given metals in contact
(*a*) can be ascertained (*b*) cannot be ascertained
(*c*) is less (*d*) is more.

412. Two cricket players A and B scored the runs of same mean and different standard deviations of 2 and 3 respectively. Then :
(*a*) B is said to be more consistent than A
(*b*) B is said to be less consistent than A
(*c*) A is said to be more consistent than B
(*d*) Both A and B have same consistency in scores.

413. For the following readings 0, 1, 2, 3, 6, 5, 4, and 5, the mean is :
(*a*) 0 (*b*) 6
(*c*) 3.25 (*d*) 3.7143.

414. Needs may come from
(*a*) customers (*b*) operating personnel
(*c*) service personnel (*d*) any one of these.

415. Effects of climate, noise and vibration are examples of .... environment study.
(*a*) physical (*b*) cognitive
(*c*) psychological (*d*) workplace.

416. The .... environment has profound effects on the attitudes of working people, their satisfaction in work and eventually the success of the company.

(*a*) physical (*b*) congnitive
(*c*) psychological (*d*) none of the above.

417. By providing .... in the system, the reliability of the system increases.

(*a*) redundancy (*b*) standby arrangement
(*c*) both (*a*) and (*b*) (*d*) series arrangement.

418. Worst-case approach used to ensure reliability leads to

(*a*) optimum design (*b*) overdesign
(*c*) under design (*d*) none of the above.

419. The causes of unreliability is/are :

(*a*) Design mistakes (*b*) Manufacturing defects
(*c*) Maintenance (*d*) All the above.

420. Social-cultural influence on design pertains to

(*a*) environmental pollution
(*b*) what people think about the design solution
(*c*) both (*a*) and (*b*)
(*d*) none of the above.

421. Dissimilar metals in contact may lead to

(*a*) corrosion (*b*) cracks
(*c*) creep (*d*) fatigue.

422. The chief concept in engineering economy is :

(*a*) Money has a time value (*b*) Control of money and trade
(*c*) Interest rate calculation (*d*) All the above.

423. The single payment compound amount factor can be used to calculate the ....

(*a*) present worth (*b*) future worth
(*c*) both (*a*) and (*b*) (*d*) none of the above.

424. Metal moulds are used in

(*a*) green sand moulding (*b*) dry sand moulding
(*c*) loam moulding (*d*) die casting process.

425. Blow holes in castings are due to

(*a*) high moisture content of the sand
(*b*) low permeability of sand
(*c*) excessive fine grains and gas producing ingredients
(*d*) any of the above.

426. Temperature developed as a result of the spark is of the order of

(*a*) 10000°C (*b*) 5000°C
(*c*) 1500°C (*d*) 2500°C.

427. Erosion of metal in EDM is

(*a*) continuous (*b*) proportionate to the number of sparks

(*c*) only for once (*d*) any of these.

428. Ergonomists sometimes alter the human user by means of ....

(*a*) redesign of machine

(*b*) replacing the equipment

(*c*) selection, training and the use of job aids

(*d*) none of the above.

429. The ergonomists are found in the field of

(*a*) design and production engineering (*b*) management services

(*c*) medicine and occupational health (*d*) all the above.

430. Optimisation by analytical methods deal with the properties of and how to find

(*a*) maxima (*b*) minima

(*c*) maxima and minima (*d*) none of the above.

431. Optimisation by analytical methods includes

(*a*) differential calculus (*b*) search methods

(*c*) linear programming (*d*) all the above.

432. The median of the readings 12, 11, 10, 8, 9, 13 is :

(*a*) 13 (*b*) 8

(*c*) 10.5 (*d*) 21.

433. Mode of the following readings 106, 107, 107, 108, 106, 107 is

(*a*) 107 (*b*) 108

(*c*) 106 (*d*) 321.

434. Average cutting speed in machining mild steel by single point tool of HSS is

(*a*) 10 m/min (*b*) 20 m/min

(*c*) 40 m/min (*d*) 50 m/min.

435. Tool life is said to be over if

(*a*) a poor surface is obtained

(*b*) sudden increase in power and cutting force with chattering takes place

(*c*) overheating and fuming takes place

(*d*) all of the above.

436. Tool life is most affected by

(*a*) cutting speed (*b*) tool geometry

(*c*) feed and depth (*d*) all of the above.

437. In compound dies

(*a*) two or more cutting operations can be performed simultaneously

(*b*) cutting and forming operations are combined

(*c*) workpiece keeps moving from one station to other station

(*d*) all of the above.

438. After cold forming, steel balls are subjected to
(*a*) normalising (*b*) tempering
(*c*) electroplating (*d*) stress relieving.

439. Which of the brazing joint is strongest ?
(*a*) Butt joint (*b*) Single scraf joint
(*c*) Lap joint (*d*) Double scraf joint.

440. In braze welding, filler metal is
(*a*) melted and deposited at the spot where weld is to be made
(*b*) distributed by explosion
(*c*) distributed by capillary action
(*d*) not required at all.

441. Metal removal in electrolytic grinding takes place
(*a*) by electrochemical action (*b*) by erosion
(*c*) by corrosion (*d*) all of the above.

442. Surface finish produced by electrochemical grinding on tungsten carbide can be expected to be of the order of
(*a*) 0.2 — 0.4 micron (*b*) 0.4 — 0.6 micron
(*c*) 0.6 — 0.8 micron (*d*) 0.8 — 0.9 micron.

443. Reliability predictions are based on
(*a*) past experience (*b*) statistical analysis
(*c*) both (*a*) and (*b*) (*d*) complexity of the product.

444. Reliability of the product (mechanical) remains .... throughout the life of the product.
(*a*) same (*b*) decreases
(*c*) increases (*d*) both (*b*) and (*c*).

445. The hardness of a grinding wheel is specified by
(*a*) letter of alphabet (*b*) BHN
(*c*) rockwell hardness no. (*d*) VPN.

446. Drilling is an example of ....
(*a*) oblique cutting (*b*) uniform cutting
(*c*) orthogonal cutting (*d*) complex cutting.

447. When drilling cast iron, the coolant used should be ....
(*a*) kerosene (*b*) compressed air
(*c*) lard oil (*d*) water with soluble air.

448. The life of a tool is mainly dependent upon
(*a*) tool geometry (*b*) cutting speed
(*c*) feed and depth (*d*) none of the above.

449. Flank wear occurs mainly on
(*a*) cutting edges
(*b*) front face
(*c*) nose part, from relief face and side relief face
(*d*) does not wear at all essential.

450. Product development process is

(*a*) the sequence of steps of activities that an enterprise employs to conceive, design and commercialize a product

(*b*) the sequence of steps of activities that an enterprise employs to compete with other products available

(*c*) the sequence of steps of activities that an enterprise employs to improve the quality of product

(*d*) none of the above.

451. Concept generation is a methodology for

(*a*) detail of a product

(*b*) approximate description and working principle and form of product to meet customer needs

(*c*) specifications of product

(*d*) any of these.

452. Concept selection is generally done in stages :

(*a*) (*i*) concept screening (*ii*) concept sorting

(*b*) (*i*) concept selection (*ii*) brainstorming

(*c*) both (*a*) and (*b*)

(*d*) none of these.

453. Selection of proper tool material in EDM is influenced by

(*a*) size of the electrode (*b*) volume of material to be removed

(*c*) surface finish required (*d*) tolerance required

(*d*) all of the above.

454. Function of dielectric fluid is :

(*a*) It acts as a coolant.

(*b*) It serves as a conducting media when ionised.

(*c*) It acts as a flushing medium in removing chips.

(*d*) All of the above.

455. The aspect of the problem formulation which is specified by the customer is called as :

(*a*) Primary design objective (*b*) Secondary design objective

(*c*) Problem identification (*d*) None of the above.

456. Problem statement should be pharased in a

(*a*) very specific way (*b*) broad way

(*c*) any way the designer wants (*d*) none of the above.

457. In ECM, the current density in the discharge of channel is of the order of

(*a*) 10,000 ampere per cm^2 (*b*) 1000 ampere per cm^2

(*c*) 100 ampere per cm^2 (*d*) 10 ampere per cm^2.

458. A complicated contour is to be made exactly in a carbide piece. Which process will be used ?

(*a*) ECM (*b*) EDM
(*c*) LBM (*d*) USM.

459. Dielectric is a must in

(*a*) EDM process (*b*) ECM process
(*c*) USM process (*d*) LBM process.

460. The procedure adopted to evaluate, maintain and improve quality standards in several stages of manufacture refers to

(*a*) product control (*b*) SQC
(*c*) quality control (*d*) process control.

461. Product control refers to

(*a*) analysis of information and data obtained from the field
(*b*) feedback to the production processes
(*c*) evaluating the quality
(*d*) all of the above.

462. The example of appraisal cost is

(*a*) rework (*b*) employee's quality training
(*c*) field complaints (*d*) quality audits.

463. In combination dies

(*a*) cutting and formation operations are combined and are carried out in single operation
(*b*) two or more cutting operations can be performed simultaneously
(*c*) either of the above
(*d*) none of the above.

464. Gear shaping is related to

(*a*) template (*b*) hob
(*c*) generating (*d*) forming.

465. How the sand is compacted in chamber in flaskless moulding ?

(*a*) By ramming properly (*b*) By squeezing in a chamber
(*c*) By exposing to the sun (*d*) None of the above.

466. Moulds in flaskless moulding are held in

(*a*) horizontal position (*b*) vertical position
(*c*) inclined position (*d*) any of the above.

467. In arc welding, arc is created between the electrode and work by

(*a*) contact resistance (*b*) voltage
(*c*) flow of current (*d*) none of the above.

468. Projection welding is

(*a*) continuous spot welding process (*b*) forge welding
(*c*) multi-spot welding process (*d*) all of these.

469. The designer can communicate in the form of

(*a*) sketches (*b*) charts
(*c*) reports (*d*) any one of the above.

470. Shaving of the diecasted parts is the process of removal of

(*a*) sprue (*b*) flash
(*c*) runner (*d*) none of the above.

471. Warped castings may be produced due to

(*a*) poor castability of cores
(*b*) non-provision of camber allowance on the pattern
(*c*) weak flasks
(*d*) any of the above.

472. Swelling of casting may occur due to

(*a*) insufficient ramming
(*b*) rapid pouring of molten metal
(*c*) insufficient weight on the moulds during pouring
(*d*) any of the above.

473. Ergonomics consideration is involved in any one of the following cases :

(*a*) A chair must be of correct height for occupant.
(*b*) A computer language must be understandable.
(*c*) Displays on a car dashboard must be readable.
(*d*) All the above.

474. Present day designer has to make assumptions about the user's characteristics to achieve a satisfactory

(*a*) design (*b*) fit between user and product
(*c*) product (*d*) none of the above.

475. The availability of equipment is directly related to ....

(*a*) down time (*b*) man-hours
(*c*) administrative time (*d*) all of these.

476. The control chart for percent defective is

(*a*) $\bar{X}$-R-chart (*b*) *p*-chart
(*c*) *pn*-chart (*d*) *c*-chart.

477. If t is the thickness of the sheet to be spot welded, then electrode tip diameter is equal is :

(*a*) $t^{1/2}$ (*b*) t
(*c*) $1.5\ t$ (*d*) $2\ t$.

478. Neutral flame has

(*a*) 1 zone (*b*) 2 zones
(*c*) 3 zones (*d*) 4 zones.

479. In a *p*-chart, if points lie above the upper control limit, it implies that the process is producing

(*a*) poor quality items (*b*) better quality items
(*c*) as per specifications (*d*) within control.

480. *p*-charts are preferred because they

(*a*) are the only means to determine the quality
(*b*) are simple in construction
(*c*) give the overall quality level at a reasonable cost
(*d*) do not confirm to the specifications.

481. Which of the following abrasives is best suited for cutting of carbides ?

(*a*) Boron
(*b*) Silicon
(*c*) Diamond
(*d*) Alumina.

482. Liquid media in which abrasive is suspended performs the following function :

(*a*) Acts as an acoustics bond between workpiece and vibratory tool.
(*b*) Helps efficient transfer of energy between workpiece and tool.
(*c*) Acts as a coolant.
(*d*) All of the above.

483. Dielectric fluid should fulfil the following properties :

(*a*) It should possess an optimum viscosity.
(*b*) It should not evolve toxic vapours or gases.
(*c*) It should be non-inflammable.
(*d*) All of the above.

484. Time required for machining by EDM in comparison to the conventional machining is

(*a*) less
(*b*) more
(*c*) equal
(*d*) any of these.

485. Investment casting uses which of the following patterns ?

(*a*) Wax pattern
(*b*) Metal pattern
(*c*) Wooden pattern
(*d*) Any of the above.

486. Tolerances in lost wax casting is of the order of :

(*a*) $\pm$ 5 mm
(*b*) $\pm$ 0.5 mm
(*c*) $\pm$ .05 mm
(*d*) $\pm$ 0.005 mm.

487. Gated patterns are used for

(*a*) mass production of small castings
(*b*) production of castings which do not require machining
(*c*) castings having several hollow spaces
(*d*) castings of light metal.

488. Skeleton patterns are used for

(*a*) small castings
(*b*) non-ferrous castings
(*c*) large castings
(*d*) hollow castings.

489. A spokeshave is a

(*a*) planning tool
(*b*) sawing tool
(*c*) layout tool
(*d*) boring tool.

490. Cohesiveness of sand depends upon
(*a*) grain size and shape of sand particles
(*b*) bonding materials
(*c*) moisture contents
(*d*) all of the above.

491. For converting electrical energy into mechanical energy, which of the effect forms the basis of USM ?
(*a*) Piezoelectric effect (*b*) Photosynthesis
(*c*) Chemical action (*d*) None of the above.

492. USM is used for
(*a*) casting and welding of metals
(*b*) forming of plastics
(*c*) measurement of velocity of the moving fluid
(*d*) all of the above.

493. In USM, metal is removed by
(*a*) action of abrasive grains (*b*) action of slurry
(*c*) reaction of a chemical (*d*) all of these.

494. Synectics is a method of problem solving by
(*a*) an individual (*b*) a group
(*c*) a designer (*d*) none of the above.

495. The synectic group consist of
(*a*) experts from diverse fields (*b*) experts from one area only
(*c*) any group of people (*d*) none of these.

496. In abrasive jet machining process, the abrasive particles should be
(*a*) of irregular shape (*b*) made of diamond powder
(*c*) perfectly round (*d*) none of the above.

497. Ultrasonic machining method is best suited for
(*a*) stainless steel (*b*) plastics
(*c*) brittle materials (*d*) lead.

498. The machining action in ultrasonic machining method is achieved by
(*a*) impact of tool on coolant (*b*) impact of tool on workpiece
(*c*) impact of tool on abrasive particles (*d*) all of these.

499. .... means the engineering methods or techniques for performing technological transformation.
(*a*) Production (*b*) Process
(*c*) Control (*d*) All of these.

500. Some of the sub-systems in the production system are :
(*a*) Decision Making and Control
(*b*) Product Development and Design for Production
(*c*) Control Information Processing and Integrated Manufacturing Systems
(*d*) All the above.

501. Chip breakers are provided on the cutting tools
(*a*) to minimize heat generation (*b*) for safety of operators
(*c*) to permit short segmented chips (*d*) to increase tool life.

502. To remove maximum metal per minute with same tool life
(*a*) increase depth of cut (*b*) increase feed rate
(*d*) decrease cutting speed (*d*) any of the above.

503. Needs may come from
(*a*) operating personnel (*b*) service personnel
(*c*) customers (*d*) any one of these.

504. Need analysis consists of
(*a*) listing the user needs for the design
(*b*) asking the needs from the sales personnel
(*c*) reducing the cost of the product
(*d*) none of the above.

505. Sweep patterns are used to prepare mould of
(*a*) symmetrical regular shapes (*b*) unsymmetrical and regular shapes
(*c*) unsymmetrical and irregular shapes (*d*) none of the above.

506. Shell patterns are often used for
(*a*) pipe works (*b*) bends
(*c*) drainage fitting (*d*) all of these.

507. The goals of the design project should result from the
(*a*) need analysis (*b*) identification of the problem
(*c*) ideation (*d*) none of these.

508. The goals of the design comprises :
(*a*) perfomance goals (*b*) time goals
(*c*) cost goals (*d*) all of these.

509. Aesthetic quality in engineering design can be achieved through
(*a*) elegance of concept (*b*) elegance of realisation
(*c*) both (*a*) and (*b*) (*d*) various ways.

510. Some concepts of aesthetics are :
(*a*) Function (*b*) Form
(*c*) Styling (*b*) All of these.

511. A burr is
(*a*) burnt sand
(*b*) a cutting tool
(*c*) sharp edge remaining on metal after cutting, stamping and machining
(*d*) built-up edge on a cutting tool.

512. Negative rake is usually provided on
(*a*) HSS tools (*b*) high carbon steel tools
(*c*) cemented carbide tools (*d*) none of the above.

513. Soldering iron is made of wedge shape is order to
(*a*) retain heat (*b*) retain solder
(*c*) apply high pressure at edge (*d*) all of these.

514. Heat for soldering process is supplied by
(*a*) induction furnace (*b*) electrical resistance method
(*c*) soldering iron (*d*) any of these.

515. Which of the following is preferred for welding of non-ferrous metals by arc welding ?
(*a*) A.C. (*b*) D.C.
(*c*) All of the above (*d*) None of the above.

516. Main function of cutting fluid is
(*a*) providing lubrication (*b*) cool the tool and workpiece
(*c*) wash away the chips (*d*) all of these.

517. Friction between tool and chip can be reduced by
(*a*) increasing rake angle (*b*) increasing shear angle
(*c*) using coolant (*d*) increasing sliding velocity.

518. A left hand tool on lathe is used for turning in the direction
(*a*) from right to left (*b*) from left to right
(*c*) across the bed (*d*) any direction.

519. Segmented chips are formed when machining
(*a*) ductile materials (*b*) brittle materials
(*c*) heat treated metal (*d*) none of the above.

520. An ideal chip is
(*a*) heavy continuous chip
(*b*) light continuous chip
(*c*) short and broken one in the shape of figure '9'
(*d*) none of the above.

521. Continuous chips are formed when machining
(*a*) ductile materials (*b*) brittle materials
(*c*) heat treated materials (*d*) any of the above.

522. The manufacturing system has
(*a*) workpiece system (*b*) tool and energy system
(*c*) information and component system (*d*) all of these.

523. Flow of material is not continuous in .... production system.
(*a*) job (*b*) batch
(*c*) mass (*d*) job and batch.

524. Morphological analysis is
(*a*) problem definition
(*b*) a systematic approach to problem definition and solution
(*c*) matrix formation
(*d*) need analysis.

525. Morphological analysis work best when the problem can be
(*a*) well defined (*b*) decomposed into subproblems
(*c*) complex (*d*) all of the above.

526. The quality maintenance of patterns and tools come under :
(*a*) appraisal cost (*b*) failure cost
(*c*) prevention cost (*d*) all of these.

527. The three basic aspects involved in any quality control programme are
(*a*) engineering, statistical and managerial
(*b*) engineering, managerial and planning
(*c*) statistical, inspection and planning
(*d*) planning inspection and engineering.

528. The search method which places the first two trial points at 0.618L from either end of the range, L is :
(*a*) Golden section search method (*b*) Sequential search method
(*c*) Uniform search method (*d*) Sequential simplex search method.

529. In sequential simplex search method, the simplex is
(*a*) a straight line (*b*) a point
(*c*) an equilateral triangle (*d*) a quadrilateral.

530. Soft information is generally
(*a*) verifiable (*b*) verbal
(*c*) nebulous (*d*) both (*b*) and (*c*).

531. Hard information is generally
(*a*) verifiable (*b*) permanent
(*c*) documentable (*d*) all of these.

532. A designer transmits pertinent and useable information in the form of
(*a*) specifications (*b*) need statement
(*c*) opinions (*d*) ideas.

533. EDM and ECM processes .... be used for machining ceramics and plastics:
(*a*) can (*b*) cannot
(*c*) either of the above (*d*) none of the above.

534. Surface integrity is considerably .... for EDM process as compared to that of ECM.
(*a*) poor (*b*) good
(*c*) excellent (*d*) very good.

535. Reasons for adopting probabilities approaches in engineering design are :
(*a*) Reliability (*b*) Theoretical validity of results
(*c*) Economic considerations (*d*) All of the above.

536. The probabilistic techniques take into consideration
(*a*) the magnitude of almost every measurable parameter to vary in a random fashion
(*b*) the magnitude of some measurable parameter to vary in a fixed way
(*c*) assign randomly the probability values to every parameter
(*d*) none of the above.

537. Closed loop system consists of
(*a*) input variables
(*b*) output variables
(*c*) transformation phase
(*d*) all of the above
(*e*) none of the above.

538. Driving of an automobile is an example of :
(*a*) Open loop system
(*b*) Closed loop system
(*c*) Automated system
(*d*) Any of these.

539. Usefulness of the design concept depends on .... which prevails when it is being used.
(*a*) user
(*b*) utility value
(*c*) both (*a*) and (*b*)
(*d*) state of nature.

540. Expected utility of the design concept includes
(*a*) probability of occurrence of different alternatives
(*b*) probability of failure of design concept
(*c*) random prediction of events
(*d*) none of the above.

541. Probabilistic design take into account the uncertainties in the
(*a*) applied load
(*b*) variability in material properties
(*c*) inaccuracies in manufacturing
(*d*) all of these.

542. VUOSO system uses
(*a*) 3 digits
(*b*) 4 digits
(*c*) 5 digits
(*d*) any of these.

543. OPITZ system uses
(*a*) 6 digits
(*b*) 4 digits
(*c*) 7 digits
(*d*) none of these.

544. CODE system is
(*a*) 2 digit system
(*b*) 5 digit system
(*c*) 8 position hexadecimal system
(*d*) any of these.

545. Which of the following uses a line type layout ?
(*a*) Shoe making industry
(*b*) Machine tool industry
(*c*) Chemical plant
(*d*) Furniture making.

546. Extrusion is a
(*a*) casting technique
(*b*) forging
(*c*) forming process
(*d*) none of these.

547. Copper is :
(*a*) easily spot welded
(*b*) difficult to be spot welded
(*c*) either of the above
(*d*) none of the above.

548. The more complex the system, the .... the required maintenance time.
(*a*) longer
(*b*) smaller
(*c*) both (*a*) and (*b*)
(*d*) none of the above.

549. The factor which furnishes clues about expected maintenance time is/are :
(*a*) Accessibility
(*b*) Warning lights
(*c*) Built-in measuring and metering device
(*d*) All the above.

550. .... is the probability that a failed system is restored to operable condition in a specified down time.
(*a*) Availability (*b*) Maintainability
(*c*) System effectiveness (*d*) Man-hours.

551. In wire drawing wire of more diameter is reduced to small diameter by pulling its one end. State whether this is right or wrong.
(*a*) Right (*b*) Wrong.

552. Sharp corners are not preferred in finished components. State whether this is right or wrong :
(*a*) Right (*b*) Wrong.

553. Main function of providing lubrication is
(*a*) to reduce frictional resistance (*b*) to increase surface finish
(*c*) to reduce machine load (*d*) all of these.

554. In machining of component, first rough shape is given then final shape is given to raw material. Is it right or wrong ?
(*a*) Right (*b*) Wrong.

555. Which of the following is a temporary joint ?
(*a*) Welding (*b*) Rivetting
(*c*) Either of the above (*d*) None of the above.

556. Powder forming is preferred for
(*a*) ferrous materials (*b*) aluminium
(*c*) hard materials (*d*) none of the above.

557. Draft allowance in powder forming process is usually
(*a*) 2° (*b*) $3^\circ - 7^\circ$
(*c*) zero draft (*d*) none of the above.

558. Two holes of diameter 5 mm are to be made in a steel sheet of 2 mm. Minimum distance between their centres will be :
(*a*) 2 mm (*b*) 5 mm
(*c*) 7 mm (*d*) 9 mm.

559. Which of the following is not a heart treatment process?
(*a*) Brazing (*b*) Annealing
(*c*) Normalising (*d*) Tempering.

560. Fillet represents
(*a*) a special type of screw
(*b*) welding in the corner
(*c*) providing round corners instead of sharp corners
(*d*) none of the above.

561. Rapid change in thickness of cross-section leads to

(*a*) more surface finish (*b*) defects like laps and cracks
(*c*) more tonnage (*d*) none of the above.

562. Equipment availability is directly related to

(*a*) down time (*b*) administrative time
(*c*) man-hours (*d*) all the above.

563. Non-ferrous cast tool steel operates best at

(*a*) cold temperatures (*b*) high temperatures of 500°C
(*c*) elevated temperatures of 825°C (*d*) none of these.

564. Carbide tool bits are grounded by following type of grinding wheel :

(*a*) Aluminium oxide (*b*) Silicon carbide
(*c*) Cobalt (*d*) Diamond.

565. For proper sawing of work, work should be supported on

(*a*) jaws (*b*) parallels
(*c*) clamps (*d*) flats.

566. Best coolant and lubricant for aluminium is

(*a*) water soluble oils (*b*) mineral and fatty oils or soluble oils
(*c*) dry (*d*) none of the above.

567. The midpoint of class interval with the highest frequency is called :

(*a*) Mean (*b*) Range
(*c*) Mode (*d*) Medium.

568. The most commonly used central tendency is :

(*a*) Mode (*b*) Medium
(*c*) Mean (*d*) None of these.

569. For drilling operation, a cylindrical should always be clamped on

(*a*) collet (*b*) vise
(*c*) jaw (*d*) V-block.

570. Cutting edges of a standard twist drill are called as

(*a*) flutes (*b*) lips
(*c*) wedges (*d*) flanks.

571. Spinning operation is carried out on

(*a*) hydraulic press (*b*) lathe
(*c*) mechanical press (*d*) drill press.

572. Thread rolling is like

(*a*) cold extrusion (*b*) cold machining
(*c*) cold rolling (*d*) cold forging.

573. Faulty material planning leads to

(*a*) excess inventory (*b*) increased cost of products
(*c*) increased production hours (*d*) all the above.

574. Production control system is necessary because it helps in

(*a*) meeting specified targets regarding delivery dates
(*b*) optimum use of man/machine-hours
(*c*) quality control
(*d*) all the above.

575. The control used for attributes are :

(*a*) $\bar{X}$ and C charts (*b*) $\bar{X}$ and R charts
(*c*) *p* and C charts (*d*) R and C charts

576. C-chart means control chart for

(*a*) defectives (*b*) defects
(*c*) range (*d*) averages.

577. The common value of the consumer's risk in the form of fraction is

(*a*) 0.10 (*b*) 0.05
(*c*) 0.01 (*d*) 0.25.

578. The effectiveness of a sampling plan can be explained by means of

(*a*) control charts for averages (*b*) an operating characteristic curve
(*c*) dodge raming curve (*d*) double sampling plan.

579. Small varieties and large volumes are manufactured in ....

(*a*) job (*b*) batch
(*c*) mass (*d*) job and batch.

580. A .... is defined as the availability of one man for one hour for doing a job.

(*a*) man-hour (*b*) machine-hour
(*c*) manufacturing time (*d*) production rate.

581. A slick is mainly used for

(*a*) making joints in moulds (*b*) providing opening in moulds
(*c*) repairing and finishing of the mould (*d*) removing pattern from the mould.

582. Swab is used for

(*a*) applying water to the mould around the edge of the pattern
(*b*) shaking pattern to facilitate its withdrawal from the mould
(*c*) repairing and finishing of the mould
(*d*) none of the above.

583. The .... is source of information for a designer.

(*a*) testing and research institutes (*b*) physical laws
(*c*) problem definition (*d*) all the above.

584. Description is a

(*a*) record of various ideas (*b*) a set of procedures
(*c*) details about product (*d*) both (*a*) and (*b*).

585. The steps like preparation, concentration, incubation, illumination, verification are encountered in following methods of design :

(*a*) Engineering (*b*) Scientific
(*c*) Creativity (*d*) None of the above.

586. The tool life is presented in the form of :

(*a*) $VT^n = C$ (*b*) $TV^n = C$

(*c*) $T^{1/n} V = C$ (*d*) $T^{2/n} V = C$.

587. In chemical machining, the mechanics of material removed is

(*a*) corrosive reaction (*b*) plastic shear

(*c*) erosion (*d*) ion displacement.

588. Resources are

(*a*) inputs to the system (*b*) money only

(*c*) raw material only (*d*) none of the above.

589. For checking the resources feasibility, we should ascertain

(*a*) enough capital (*b*) profit

(*c*) availability (*d*) all the above.

590. Design by evolution is a

(*a*) very fast method of designing (*b*) slow process of product development

(*c*) trial and error method (*d*) none of these.

591. Design by evolution involves

(*a*) single product development approach

(*b*) systems approach

(*c*) traditional design approach

(*d*) none of the above.

592. Undercutting is the operation of cutting

(*a*) below the specified size (*b*) a deep groove

(*c*) a groove next to shoulder (*d*) with high depth of cut.

593. The following gauge is used for the checking of holes :

(*a*) Ring gauge (*b*) Snap gauge

(*c*) Plug gauge (*d*) Dial gauge.

594. Chisels for metal cutting are hardened

(*a*) at tip (*b*) all over

(*c*) at cutting edge (*d*) at top.

595. Most machinable metal is one which

(*a*) produces discontinuous chips

(*b*) permits maximum metal removal per tool grind

(*c*) results in minimum value of shear angle

(*d*) all of the above.

596. Metal is machining operation is removed by

(*a*) tearing chips (*b*) shearing the metal across the zone

(*c*) distorsion of metal (*d*) extruding the metal with tool.

597. Best all round coolant for carbide tools is

(*a*) soluble oil (*b*) kerosene

(*c*) compressed air (*d*) soap water.

598. A right hand tool on lathe cuts most efficiently when tool travels
(*a*) from left to right end of lathe bed (*b*) from right to left end of lathe bed
(*c*) any of the above (*d*) none of these.

599. Product control refers to the schemes for evaluating the quality of
(*a*) incoming material (*b*) outgoing product
(*c*) inprocess product (*d*) purchased product.

600. The main aim of statistical quality control in industrial application is to have
(*a*) better quality at lower cost (*b*) better quality at higher cost
(*c*) better quality at any cost (*d*) medium cost at any quality.

601. If the lower control limit has a negative value in the *p*-chart, then it is
(*a*) treated as negative only (*b*) equated to zero
(*c*) equated to unity (*d*) eliminated from the chart.

602. To know whether the process is in a state of control or not, it is necessary to
(*a*) calculate the fraction defective (*b*) calculate percent defective
(*c*) compute trial control limits (*d*) calculate average percent defective.

603. In die casting process
(*a*) molten metals is fed into the cavity in metallic mould by gravity
(*b*) metal is forced into mould under high pressure
(*c*) cavity is filled with a pre-calculated quantity of metal and a plunger is inserted to force the metal into cavity
(*d*) none of the above.

604. Shell moulding process requires
(*a*) sand patterns (*b*) plastic patterns
(*c*) metal patterns (*d*) none of the above.

605. Incubation means
(*a*) period of direct labour
(*b*) time gap between preparation and illumination
(*d*) thinking about problem
(*d*) collection of details of problem.

606. The characteristic features of creativity are
(*a*) custom (*b*) habit
(*c*) tradition (*d*) none of the above.

607. In coated electrodes in arc welding
(*a*) rod and coating melt simultaneously
(*b*) rod melts first and then coating melts
(*c*) it depends on polarity
(*d*) none of the above.

608. In reverse polarity welding
(*a*) electrode holder is connected to negative and work to positive
(*b*) electrode holder is connected to positive and work to negative
(*c*) work is negative and holder is earthed
(*d*) any of the above.

609. .... is a detailed analysis of the malfunction that can be produced on the components of an engineering system.
(*a*) Hazard analysis (*b*) FMEA
(*c*) Fault hazard analysis (*d*) All the above.

610. Phenomenon of weld decay occurs in
(*a*) cast iron (*b*) bronze
(*c*) stainless steel (*d*) brass.

611. Weaving in arc welding refers to :
(*a*) side to side motion of electrode at right angle to the direction of welding
(*b*) spiral motion of electrode
(*c*) arc blow action due to pressure applied
(*d*) none of the above.

612. Weld spatter is a
(*a*) welding defect (*b*) flux
(*c*) catalyst (*d*) welding technique.

613. Tool signature comprises of
(*a*) 4 elements (*b*) 5 elements
(*c*) 6 elements (*d*) 7 elements.

614. Cutting force with increase in nose radius of a single point cutting tool will
(*a*) increase slightly (*b*) decrease slightly
(*c*) remain unchanged (*d*) increase considerably.

615. Optimum rake angle of a tool is a function of
(*a*) cutting speed (*b*) cutting tool material
(*c*) properties of work material (*d*) feed and depth of cut.

616. Back rake angle of HSS single point cutting tool for machining brass is
(*a*) 10° (*b*) –5°
(*c*) 0° (*d*) +5°

617. Long wires are made by
(*a*) extrusion (*b*) rolling
(*c*) drawing (*d*) swaging.

618. External screw threads can be produced by
(*a*) milling (*b*) shaping
(*c*) rolling (*d*) casting.

619. Why welding is preferred to riveting in structural work ?
(*a*) It is quieter (*b*) It is cheaper
(*c*) It is more flexible (*d*) None of the above.

620. In resistance welding, pressure is released
(*a*) no pressure is applied (*b*) after the weld cools
(*c*) during heating period (*d*) any of the above.

621. The detail drawing of the component or product help to result into
(*a*) bill of material (*b*) resource planning
(*c*) tool planning (*d*) machine planning.

622. Symmetrical hollow parts of circular section are made by

(*a*) hot forging (*b*) hot extrusion

(*c*) hot drawing (*d*) hot spinning.

623. Collapsible toothpaste tubes are made by which of the following processes ?

(*a*) Direct extrusion (*b*) Indirect extrusion

(c) Impact extrusion (*d*) Injection moulding.

624. In order to provide effective maintainability, which factors are considered early in the design and are continually refined as the design process :

(*a*) Repair policies.

(*b*) Analysis and prediction of maintainability.

(*c*) Design factors affecting maintainability.

(*d*) All of the above.

625. Human factors affecting maintainability are :

(*a*) Environmental effects.

(*b*) Selecting repair policy.

(*c*) Developing calibration and adjustment procedures.

(*d*) All of the above.

626. Blind, risers

(*a*) supply the hotest metal when pouring is completed

(*b*) assist in feeding the metal into casting proper

(*c*) do not exist

(*d*) none of the above.

627. Loose piece patterns are

(*a*) used when the pattern cannot be drawn from the mould

(*b*) similar to the core prints

(*c*) never used in foundry work

(*d*) none of the above.

628. Wood for pattern is considered dry when moisture content is

(*a*) less than 15% (*b*) less than 30%

(*c*) zero per cent (*d*) none of the above.

629. The purpose of spruce is to

(*a*) feed molten metal from pouring basin to gate

(*b*) act as a reservoir for molten metal

(*c*) help to feed the casting until all solidification takes place

(*d*) none of the above.

630. A simple method of optimising is differential calculus where the derivative is

(*a*) zero at the maximum point

(*b*) zero at the minimum point

(*c*) maximum at the maximum point

(*d*) both (*a*) and (*b*).

631. Search method of optimisation is used where engineering problems .... be expressed by simple analytical functions.
(*a*) can (*b*) cannot
(*c*) both (*a*) and (*b*) (*d*) none of the above.

632. The melting point of the filler metal in brazing should be above
(*a*) 600°C (*b*) 900°C
(*c*) 1000°C (*d*) 420°C.

633. The most commonly used flame in gas welding is
(*a*) oxidising (*b*) carburising
(*c*) neutral (*d*) none of the above.

634. When the available data are free from error, the search is called
(*a*) deterministic (*b*) stochastic
(*c*) probability (*d*) none of the above.

635. When the available data are subject to experimental or human error, the search is called ....
(*a*) deterministic (*b*) stochastic
(*c*) probability (*d*) none of the above.

636. It is required to reduce a slab directly to strip in one pass. Which of the following rolling mill will be preferred ?
(*a*) Two high rolling mill (*b*) Four high rolling mill
(*c*) Planetary mill (*d*) Reversing mill.

637. In four high rolling mill, the bigger rollers are called as :
(*a*) Guide roll (*b*) Backup rolls
(*c*) Support rolls (*d*) Powered rollers.

638. People .... small departures from optimal designs of the equipment they use and the environments they live and work in.
(*a*) cannot tolerate (*b*) can tolerate
(*c*) can be forced to tolerate (*d*) cannot ignore.

639. There is a .... to the amount of adaptation a person may reasonably be asked to make.
(*a*) no limit (*b*) limit
(*c*) fixed percentage (*d*) none of the above.

640. Metal removal rate in USM with increase in frequency of oscillation of tool
(*a*) increases
(*b*) decreases
(*c*) first increases then becomes constant
(*d*) first decreases then becomes constant.

641. In ECM, metal removal rate
(*a*) depends on the hardness of tool material
(*b*) depends on the hardness of job material
(*c*) is independent of the hardness of tool and work material
(*d*) none of these.

642. A characteristic feature of .... process of design was the absence of any visible channels of information from one designer to another.

(*a*) slow evolutionary (*b*) fast evolutionary
(*c*) slow innovative (*d*) all the above.

643. Design by evolution is used by

(*a*) craftman (*b*) engineering designer
(*c*) industrial designer (*d*) all the above.

644. Recognising the parameters essential to the design is very important during

(*a*) feasibility study (*b*) detail design
(*c*) need analysis (*d*) morphological analysis.

645. Tool cone is made of

(*a*) titanium (*b*) copper
(*c*) aluminium (*d*) any of the above.

646. Tool tip is attached to the tool cone by

(*a*) silver soldering (*b*) by nut and bolt
(*c*) by welding (*d*) by press fitting.

647. Examples of open loop system are :

(*a*) Watch
(*b*) Watch and metal cutting machine
(*c*) Watch, metal cutting and metal working machine
(*d*) All of the above.

648. Examples of closed loop system are :

(*a*) Thermostat (*b*) Watch
(*c*) Watch and Metal cutting machine (*d*) None of the above.

649. .... is that portion of down time needed for administrative work effected in doing the maintenance.

(*a*) Active repair time (*b*) Logistic time
(*c*) Administrative time (*d*) Man-hours.

650. .... is the sum of the times all technicians worked on the system during a given maintenance action.

(*a*) Active repair time (*b*) Logistic time
(*c*) Administrative time (*d*) Man-hours.

651. Helical grooves when extending full length of the drill body are called

(*a*) lips (*b*) cutting edges
(*c*) flutes (*d*) shanks.

652. Number of helical grooves which are present in a standard twist drill is usually

(*a*) One (*b*) Two
(*c*) Three (*d*) None of these.

653. If the rate of increase of favourable evidence with expenditure is high, the intensity of belief in a realisable outcome will be correspondingly ....

(*a*) high (*b*) low
(*c*) unpredictable (*d*) none of the above.

654. If any of the sub-problems suggests solutions that quickly appear to be physically realisable within given budget, then it is termed

(*a*) resolvable (*b*) tractable
(*c*) feasible (*d*) all of the above

655. The statement of the need is important because it decides the

(*a*) cost (*b*) constraints
(*c*) problem definition (*d*) all of the above.

656. The department responsible for providing the customer with the means of realising fully the intended function of the product is

(*a*) packaging and shipping (*b*) statistical quality control
(*c*) purchasing (*d*) product service.

657. The inspection of incoming materials is conducted by :

(*a*) Purchase department (*b*) Manufacturing department
(*c*) Design department (*d*) Sales department.

658. Control charts used for number of defectives are

(*a*) *c*-chart (*b*) *p*-chart
(*c*) *pn*-chart (*d*) *p*- and *c*-chart.

659. The number of defectives is the product of sample size and the

(*a*) fraction defective (*b*) defects
(*c*) defectives (*d*) any of the above.

660. .... is defined as the assignment of work to a facility (man or machine).

(*a*) Routing (*b*) Loading
(*c*) Scheduling (*d*) Dispatching.

661. .... is defined as the specification of the time and sequence in which the work is to be done.

(*a*) Routing (*b*) Loading
(*c*) Scheduling (*d*) Dispatching.

662. .... is defined to ensure that what is intended and planned is being implemented and achieved.

(*a*) Routing (*b*) Loading
(*c*) Scheduling (*d*) Follow-up.

663. MRR will .... with increase of abrasive slurry concentration.

(*a*) increase (*b*) first increase then decrease
(*c*) first decrease then increase (*d*) first increase then become constant.

664. In EDM process the workpiece is generally connected to

(*a*) positive (*b*) negative
(*c*) earth (*d*) any of these.

665. Metal removal rate (MRR) in USM is more for

(*a*) larger grain size of abrasive (*b*) smaller grain size of abrasive
(*c*) medium grain size of abrasive (*d*) none of the above.

666. .... is the probability that a given test item will fail between t_1 and t_2 when it already has survived to t_1.

(*a*) Unreliability (*b*) Reliability
(*c*) Hazard rate (*d*) None of the above.

667. The hazard or failure rate is expressed as :

(*a*) 1 percent per 1000 hour (*b*) 10^{-5} per hour
(*c*) both (*a*) and (*b*) (*d*) a ratio

668. Firing of a missile is an example of

(*a*) open loop system (*b*) closed loop system
(*c*) either of the above (*d*) none of the above.

669. Working of a thermostat is an example of

(*a*) closed system (*b*) open system
(*c*) automated system (*d*) any of the above.

670. Most of the .... components do not exhibit a region of constant failure rate.

(*a*) mechanical (*b*) electronic
(*c*) plastic (*d*) all the above.

671. Scabs may be caused by

(*a*) low permeability of sand
(*b*) high moisture content of sand
(*c*) intermittent running of molten metal over the sand surface
(*d*) any of the above.

672. The property of sand to withstand high temperature of molten metal without fusion or breakdown is known as :

(*a*) Refractoriness (*b*) Cohesiveness
(*c*) Porosity (*d*) Adhesiveness.

673. Design review provides a systematic method for identifying

(*a*) problems with the design (*b*) various aspects of design
(c) stages of design (*d*) design requirements.

674. The important aesthetic design requirements are :

(*a*) Appearance (*b*) Attractive colours and desired finish
(*c*) Human factor consideration (*d*) All the above.

675. For turning mild steel, type of tool used is

(*a*) right hand type (*b*) left hand type
(*c*) any one of the above two (*d*) none of the above.

ANSWERS

1. (*c*)	**2.** (*c*)	**3.** (*c*)	**4.** (*c*)	**5.** (*a*)	**6.** (*b*)
7. (*a*)	**8.** (*b*)	**9.** (*d*)	**10.** (*c*)	**11.** (*b*)	**12.** (*b*)
13. (*c*)	**14.** (*c*)	**15.** (*d*)	**16.** (*c*)	**17.** (*b*)	**18.** (*b*)

19. (*b*)	20. (*c*)	21. (*d*)	22. (*c*)	23. (*d*)	24. (*b*)
25. (*c*)	26. (*a*)	27. (*a*)	28. (*d*)	29. (*c*)	30. (*d*)
31. (*d*)	32. (*a*)	33. (*b*)	34. (*a*)	35. (*d*)	36. (*c*)
37. (*d*)	38. (*b*)	39. (*c*)	40. (*a*)	41. (*a*)	42. (*a*)
43. (*a*)	44. (*d*)	45. (*d*)	46. (*a*)	47. (*b*)	48. (*b*)
49. (*d*)	50. (*d*)	51. (*d*)	52. (*c*)	53. (*a*)	54. (*b*)
55. (*d*)	56. (*b*)	57. (*a*)	58. (*b*)	59. (*c*)	60. (*d*)
61. (*a*)	62. (*d*)	63. (*d*)	64.(*c*)	65. (*d*)	66. (*e*)
67. (*b*)	68. (*c*)	69. (*a*)	70. (*d*)	71. (*c*)	72. (*a*)
73. (*a*)	74. (*c*)	75. (*c*)	76. (*d*)	77. (*a*)	78. (*b*)
79.(*a*)	80. (*d*)	81. (*d*)	82. (*c*)	83. (*a*)	84. (*c*)
85. (*a*)	86. (*c*)	87. (*a*)	88. (*a*)	89. (*c*)	90. (*a*)
91. (*b*)	92. (*b*)	93. (*c*)	94. (*c*)	95. (*a*)	96. (*a*)
97. (*d*)	98. (*a*)	99. (*c*)	100. (*c*)	101. (*a*)	102. (*a*)
103. (*c*)	104. (*a*)	105. (*a*)	106. (*b*)	107. (*c*)	108. (*c*)
109. (*e*)	110. (*a*)	111. (*a*)	112. (*a*)	113. (*b*)	114. (*a*)
115. (*b*)	116. (*a*)	117. (*b*)	118. (*c*)	119. (*b*)	120. (*b*)
121. (*a*)	122. (*c*)	123. (*b*)	124. (*a*)	125. (*c*)	126. (*a*)
127. (*a*)	128. (*a*)	129. (*a*)	130. (*a*)	131. (*a*)	132. (*b*)
133. (*b*)	134. (*d*)	135. (*c*)	136. (*a*)	137. (*d*)	138. (*b*)
139. (*a*)	140. (*b*)	141. (*b*)	142. (*d*)	143. (*a*)	144. (*b*)
145. (*b*)	146. (*b*)	147. (*b*)	148. (*b*)	149. (*d*)	150. (*c*)
151. (*b*)	152. (*a*)	153. (*c*)	154. (*a*)	155. (*a*)	156. (*a*)
157. (*b*)	158. (*c*)	159. (*d*)	160. (*c*)	161. (*b*)	162. (*c*)
163. (*d*)	164. (*c*)	165. (*c*)	166. (*d*)	167. (*a*)	168. (*b*)
169. (*a*)	170. (*c*)	171. (*b*)	172. (*d*)	173. (*b*)	174. (*a*)
175. (*b*)	176. (*d*)	177. (*d*)	178. (*c*)	179. (*d*)	180. (*b*)
181. (*b*)	182. (*c*)	183. (*a*)	184. (*b*)	185. (*b*)	186. (*b*)
187. (*a*)	188. (*b*)	189. (*a*)	190. (*d*)	191. (*a*)	192. (*b*)
193. (*c*)	194. (*c*)	195. (*c*)	196. (*a*)	197. (*a*)	198. (*a*)
199. (*a*)	200. (*a*)	201. (*b*)	202. (*a*)	203. (*b*)	204. (*a*)
205. (*d*)	206. (*a*)	207. (*a*)	208. (*c*)	209. (*b*)	210. (*b*)
211. (*d*)	212. (*d*)	213. (*d*)	214. (*d*)	215. (*d*)	216. (*b*)
217. (*a*)	218. (*b*)	219. (*a*)	220. (*b*)	221. (*d*)	222. (*d*)
223. (*b*)	224. (*a*)	225. (*a*)	226. (*a*)	227. (*b*)	228. (*a*)
229. (*a*)	230. (*a*)	231. (*a*)	232. (*c*)	233. (*d*)	234. (*d*)
235. (*a*)	236. (*a*)	237. (*d*)	238. (*c*)	239. (*a*)	240. (*d*)
241. (*b*)	242. (*a*)	243. (*d*)	244. (*d*)	245. (*c*)	246. (*c*)
247. (*b*)	248. (*a*)	249. (*b*)	250. (*d*)	251. (*a*)	252. (*b*)
253. (*c*)	254. (*a*)	255. (*b*)	256. (*b*)	257. (*c*)	258. (*b*)
259. (*b*)	260. (*a*)	261. (*b*)	262. (*b*)	263. (*d*)	264. (*a*)

265. (*b*)	266. (*d*)	267. (*d*)	268. (*d*)	269. (*d*)	270. (*b*)
271. (*b*)	272. (*d*)	273. (*b*)	274. (*a*)	275. (*b*)	276 (*a*)
277. (*a*)	278. (*c*)	279. (*a*)	280. (*a*)	281. (*b*)	282. (*c*)
283. (*a*)	284. (*d*)	285. (*a*)	286. (*d*)	287. (*c*)	288. (*d*)
289. (*b*)	290. (*c*)	291. (*c*)	292. (*a*)	293. (*b*)	294. (*a*)
295. (*b*)	296. (*b*)	297. (*a*)	298. (*b*)	299. (*b*)	300. (*c*)
301. (*a*)	302. (*a*)	303. (*c*)	304. (*d*)	305. (*d*)	306. (*c*)
307. (*c*)	308. (*c*)	309. (*d*)	310. (*d*)	311. (*a*)	312. (*a*)
313. (*a*)	314. (*a*)	315. (*d*)	316. (*a*)	317. (*a*)	318. (*c*)
319. (*c*)	320. (*a*)	321. (*d*)	322. (*a*)	323. (*d*)	324. (*a*)
325. (*a*)	326. (*c*)	327. (*d*)	328. (*a*)	329. (*d*)	330. (*d*)
331. (*d*)	332. (*d*)	333. (*a*)	334. (*b*)	335. (*c*)	336. (*a*)
337. (*a*)	338. (*b*)	339. (*a*)	340. (*c*)	341. (*a*)	342. (*d*)
343. (*a*)	344. (*b*)	345. (*b*)	346. (*a*)	347. (*d*)	348. (*b*)
349. (*a*)	350. (*b*)	351. (*e*)	352. (*a*)	353. (*c*)	354. (*a*)
355. (*c*)	356. (*a*)	357. (*d*)	358. (*a*)	359. (*b*)	360. (*d*)
361. (*b*)	362. (*c*)	363. (*b*)	364. (*c*)	365. (*c*)	366. (*d*)
367. (*c*)	368. (*c*)	369. (*a*)	370. (*c*)	371. (*a*)	372. (*d*)
373. (*a*)	374. (*b*)	375. (*d*)	376. (*c*)	377. (*c*)	378. (*d*)
379. (*e*)	380. (*a*)	381. (*c*)	382. (*b*)	383. (*c*)	384. (*a*)
385. (*b*)	386. (*b*)	387. (*c*)	388. (*c*)	389. (*a*)	390. (*b*)
391. (*d*)	392. (*a*)	393. (*a*)	394. (*b*)	395. (*a*)	396. (*c*)
397. (*b*)	398. (*d*)	399. (*a*)	400. (*b*)	401. (*b*)	402. (*d*)
403. (*d*)	404. (*d*)	405. (*d*)	406. (*a*)	407. (*a*)	408. (*a*)
409. (*a*)	410. (*b*)	411. (*a*)	412. (*b*)	413. (*c*)	414. (*d*)
415. (*a*)	416. (*b*)	417. (*c*)	418. (*b*)	419. (*d*)	420. (*c*)
421. (*a*)	422. (*a*)	423. (*c*)	424. (*d*)	425. (*d*)	426. (*a*)
427. (*b*)	428. (*c*)	429. (*d*)	430. (*c*)	431. (*d*)	432. (*c*)
433. (*a*)	434. (*c*)	435. (*d*)	436. (*a*)	437. (*b*)	438. (*d*)
439. (*c*)	440. (*a*)	441. (*a*)	442. (*a*)	443. (*c*)	444. (*b*)
445. (*a*)	446. (*a*)	447. (*b*)	448. (*b*)	449. (*c*)	450. (*a*)
451. (*b*)	452. (*b*)	453. (*e*)	454. (*d*)	455. (*a*)	456. (*b*)
457. (*c*)	458. (*b*)	459. (*a*)	460. (*d*)	461. (*d*)	462. (*d*)
463. (*b*)	464. (*b*)	465. (*b*)	466. (*b*)	467. (*a*)	468. (*c*)
469. (*d*)	470. (*b*)	471. (*c*)	472. (*d*)	473. (*d*)	474. (*b*)
475. (*a*)	476. (*b*)	477. (*a*)	478. (*b*)	479. (*a*)	480. (*d*)
481. (*a*)	482. (*d*)	483. (*d*)	484. (*a*)	485. (*a*)	486. (*b*)
487. (*a*)	488. (*c*)	489. (*c*)	490. (*d*)	491. (*a*)	492. (*d*)
493. (*a*)	494. (*b*)	495. (*a*)	496. (*a*)	497. (*c*)	498. (*c*)
499. (*b*)	500. (*d*)	501. (*c*)	502. (*a*)	503. (*d*)	504. (*a*)
505. (*a*)	506. (*d*)	507. (*a*)	508. (*d*)	509. (*c*)	510. (*d*)

511. (*c*)	**512.** (*c*)	**513.** (*a*)	**514.** (*d*)	**515.** (*b*)	**516.** (*b*)
517. (*d*)	**518.** (*b*)	**519.** (*b*)	**520.** (*c*)	**521.** (*a*)	**522.** (*d*)
523. (*d*)	**524.** (*b*)	**525.** (*b*)	**526.** (*c*)	**527.** (*a*)	**528.** (*a*)
529. (*c*)	**530.** (*d*)	**531.** (*d*)	**532.** (*a*)	**533.** (*b*)	**534.** (*a*)
535. (*d*)	**536.** (*a*)	**537.** (*e*)	**538.** (*b*)	**539.** (*d*)	**540.** (*a*)
541. (*d*)	**542.** (*c*)	**543.** (*d*)	**544.** (*c*)	**545.** (*c*)	**546.** (*c*)
547. (*b*)	**548.** (*a*)	**549.** (*d*)	**550.** (*b*)	**551.** (*a*)	**552.** (*a*)
553. (*d*)	**554.** (*a*)	**555.** (*b*)	**556.** (*c*)	**557.** (*c*)	**558.** (*c*)
559. (*a*)	**560.** (*c*)	**561.** (*b*)	**562.** (*a*)	**563.** (*c*)	**564.** (*d*)
565. (*b*)	**566.** (*b*)	**567.** (*c*)	**568.** (*c*)	**569.** (*d*)	**570.** (*b*)
571. (*b*)	**572.** (*c*)	**573.** (*d*)	**574.** (*d*)	**575.** (*c*)	**576.** (*b*)
577. (*a*)	**578.** (*b*)	**579.** (*c*)	**580.** (*a*)	**581.** (*c*)	**582.** (*a*)
583. (*a*)	**584.** (*d*)	**585.** (*c*)	**586.** (*a*)	**587.** (*d*)	**588.** (*a*)
589. (*d*)	**590.** (*b*)	**591.** (*a*)	**592.** (*c*)	**593.** (*c*)	**594.** (*a*)
595. (*b*)	**596.** (*b*)	**597.** (*a*)	**598.** (*b*)	**599.** (*c*)	**600.** (*a*)
601. (*b*)	**602.** (*c*)	**603.** (*b*)	**604.** (*c*)	**605.** (*b*)	**606.** (*d*)
607. (*b*)	**608.** (*b*)	**609.** (*b*)	**610.** (*c*)	**611.** (*a*)	**612.** (*a*)
613. (*d*)	**614.** (*b*)	**615.** (*c*)	**616.** (*c*)	**617.** (*c*)	**618.** (*c*)
619. (*a*)	**620.** (*b*)	**621.** (*d*)	**622.** (*d*)	**623.** (*c*)	**624.** (*d*)
625. (*a*)	**626.** (*a*)	**627.** (*a*)	**628.** (*a*)	**629.** (*a*)	**630.** (*b*)
631. (*a*)	**632.** (*d*)	**633.** (*c*)	**634.** (*a*)	**635.** (*b*)	**636.** (*c*)
637. (*b*)	**638.** (*b*)	**639.** (*b*)	**640.** (*c*)	**641.** (*c*)	**642.** (*a*)
643. (*d*)	**644.** (*d*)	**645.** (*a*)	**646.** (*a*)	**647.** (*b*)	**648.** (*a*)
649. (*c*)	**650.** (*d*)	**651.** (*c*)	**652.** (*b*)	**653.** (*a*)	**654.** (*b*)
655. (*d*)	**656.** (*a*)	**657.** (*a*)	**658.** (*c*)	**659.** (*a*)	**660.** (*b*)
661. (*c*)	**662.** (*d*)	**663.** (*d*)	**664.** (*a*)	**665.** (*a*)	**666.** (*c*)
667. (*c*)	**668.** (*b*)	**669.** (*c*)	**670.** (*a*)	**671.** (*c*)	**672.** (*a*)
673. (*a*)	**674.** (*d*)	**675.** (*b*)			

II. Complete the statement with the most appropriate answer from the set :

1. Reliability of a component can be considered as ....

   (the factor of safety; the probability of survival under normal operating conditions; the ability of the component to take the overload; the probability of survival under all circumstances)

2. .... has maximum influence on surface finish in machining.

   (Cutting speed; Feed rate; Depth of cut; Lubricant)

3. There is a trade-off between cost and .... of a product.

   (brand name; reliability; complexity; popularity)

4. The basic objective of a designer is .... in meeting the client's need and society's resources.

   (conservation; optimization; minimization; maximization)

5. Flexible manufacturing cells and systems are generally applied in ....
(high variety; low volume production; medium volume; medium variety production; low variety, low volume production; low variety, high volume production).
6. In the production process control charts are used for ....
(feedback control; NC machine tool control; statistical quality control; product drawing and description)
7. .... uses mechanical energy as the principal source of energy.
(EDM; ECM; USM; LBM)
8. In brazing .... of surfaces is not a function of flux.
(removal of oxide film; promotion of wetting; chemical etching; protection)
9. Good design requires both ....
(large manpower and many machines ; money and time ; analysis and synthesis; Goverment approval and company approval)
10. Reliability can be considered as .... (the same as the factor of safety; the probability of survival of a component; the probability that the component will function without any maintenance; the ability of a component to take overload).
11. The creative process can be considered to be .... (a mystical experience of inner mind; a bio-feedback process; a team experience; a process of forming new combinations from pieces or ideas).
12. .... get first preference in design.
(Cost considerations; Outward appearance and finish; Functional requirements; Size considerations).
13. Design of geometrical shapes can be considered as ....
(the detail design step; the variant design step; the embodiment design step; the adaptive design step).
14. The preferred numbers between 10 and 100 are ....
[(10, 16, 25, 63, 100); (10,28, 46, 64, 82, 100); (10,20, 40, 60, 80, 100)]
15. Temperature in arc welding is .... (2300°C, 3600°C, 6300°C).
16. $\frac{10000}{\sqrt{2\pi}} \int_{-3}^{3} e^{-\frac{z^2}{2}} dz =$ .... (9500, 9973, 9900, 9999)
17. Two successive numbers after 5 and 8 in Fibonacci series are ....
(11, 14; 13,21; 40, 20)
18. A large metal sheet can be shaped economically into a dome with ....
(magnetic pulse forming; explosive forming; spin forming; shot peening).
19. Bath-tub curve is used in.............
(life-cycle costing; failure rate analysis; ABC analysis; Ishikawa analysis).
20. Solder material used for joining metal parts is composed of .... and ....
21. Two types of production systems are .... and ....

22. The process of design by evolution adopted by craftsman is ....
(a very fast process; a process that can be used in mass production; a slow process of design development; a process that generates an optimal design).
23. Giving detailed dimensions, tolerances, finishes and other engineering information are provided at the .... stage.
(conceptual design; creative design; configuration design; detailed design; optimal design).
24. .... is one of the most powerful aids to creativity in design.
(use of analogy; use of dreams; use of conventional old habits; use of religious beliefs; use of musical notes).
25. Designing for function involves the use and knowledge of ....
(engineering economics; labour relations; engineering sciences; production process; man-machine interactions).
26. One of the methods of increasing reliability of a system is to ....
(increase the cost of the system; increase the redundancy in the system; decrease the weight of the system; increase the factor of safety of all components; decrease the number of components in the system).

ANSWERS

1. Probability of survival under normal operation conditions 2. Cutting speed
3. Reliability 4. Optimization
5. Low variety, high volume production 6. Statistical quality control
7. USM 8. Chemical etching 9. Analysis and synthesis
10. The probability of survival of a component
11. A process of forming new combinations from pieces or ideas
12. Functional requirements 13. Mechanical design step 14. 10, 16, 25, 40, 63, 100
15. 6300°C 16. 9973 17. 13, 21
18. Explosive forming 19. life cycle costing 20. tin, lead
21. Batch type, mass production 22. slow process of design development
23. detailed design 24. Use of analogy 25. engineering sciences
26. increase the redundancy in the system.

III. Fill in the Blanks :

1. Two important classes of die casting machines are
(*a*) .... (*b*) ....
2. The casting methods that use metallic molds are
(*a*) .... (*b*) ....
3. Ultrasonic machining is carried out with tool vibration frequency in the range of .... to............
4. In Laser beam machining the energy density normally lies in the range of .... to............ W/m^2

5. The two main classes of welding process are ....
(*a*) .... (*b*) ....
6. Weldability rating could be based on
(*a*) .... (*b*) .... (*c*) ....
7. Common types of fillers used in brazing are
(*a*) .... (*b*) .... (*c*) ....
8. Draft on pattern for casting is .... to facilitate its removal from mould.
9. Cores are used to make desired .... in design.
10. Runner is provided in the moulds for .... molten metal.
11. Copper is very .... to be spot welded.
12. Forging of plain carbon steel is carried out at around .... °C.
13. Laser is produced by ....
14. The usual ratio of forward and return timings in shaping tools is ....
15. The machining action in ultrasonic machining method is achieved by impact of tool on .... particles.
16. The difference between the upper limit and lower limit of a dimension is called ....
17. The diameter of a rivet hole is usually .... than the nominal diameter of the rivet.
18. The two batch manufacturing system currently in use are job shop and .... manufacturing system.
19. Cast iron and steel pipes are produced by true casting ....
20. The media necessary for corrosion to take place is ....
21. Seam welding is a .... spot welding process.
22. The .... in depth of cut and feet rate deteriorates surface finish.
23. The tool life decreases as the cutting speed ....
24. In electro-discharge machining the .... is connected to cathode.
25. External screw threads can be produced by ....
26. Modern design problems cannot be handled by .... methods.
27. A screw is specified by its .... diameter.
28. The two rolls in a high rolling mills are of .... size.
29. A casting defect which results in general enlargement of a casting is known as.............
30. A process of removing metal by pushing or pulling a cutting tools is called ....
31. Dielectric is used in .... process.
32. In ultrasonic machining, tool is made of .... or copper.
33. The input to a complex sensor interface must be an .... signal.
34. .... network consists of a single main transmission line to which the individual devices are attached.
35. Full implementation of computer integrated manufacturing results in the automation of the .... flow through every aspect of the company's organisation.
36. Cast-iron during machining produces .... chips.
37. The act of restoring the cutting ability of a grinding wheel is known as ....

38. Dielectric is used in .... machining process.
39. Blank holding pressure is applied during .... drawing.
40. The best method for welding large sections is .... welding.
41. Lapping is a finishing operation for .... surfaces.
42. For obtaining small, intricate castings the most commonly used method is .... casting.
43. One of the most frequently used simple contact sensors is the ....
44. Tool signature comprises of .... elements.
45. Automated guided vehicles are .... powered material handling systems.
46. Every product is made in response to .... of individual or society.
47. A designer's objective is always to seek an .... solution, to meet the consumer's needs using the limited available resources.
48. The cost of .... maintenance is less than the average cost of repair after breakdown.
49. Cold-working results in loss of .... and increase of strength and hardness of metal.
50. Carbide tools wear out faster at .... speeds.
51. .... is the creative act.
52. The objective of brainstorming is to generate ....
53. A small tolerance results in greater ease of ....
54. The three stages of design are .... design, ... design, and .... design.
55. The best desing for a given objective function is called .... design.
56. Sudden and complete failure of a system is generally called .... failure.
57. .... is provided on a pattern to facilitate its removal from the mould.
58. Maximum heat in metal cutting is generated at the ....
59. The most commonly used flame in gas welding is the .... flame (oxy-acetylene).
60. Material removal in laser beam machining is due to .... and .... of workpiece material.
61. Investment casting process is most suitable for producing .... shapes.
62. Tolerances are poor in hot working because of 'shrinkage' and ....
63. In EDM metal removal is due to .... of work material.
64. In brazing bonding requires ....
65. For metal cutting tools, the most important material property is ....
66. Ease of application is another important trail of the .... planning system.
67. Low maintenance requirements are the final objective of a process .... systems.
68. The variant approach to process planning is a .... assisted.
69. Sensor control unit (SCU) provides .... information about the scene to be analysed.
70. The most useful cameral for machine vision is the solid state matrix array camera, which was desingned for military space use. This camera consists of grid light sensitive elements called picture elements or ....
71. Automated guided vehicles are .... powered material handling systems.
72. Checklist of designs are made to find .... and ....
73. Basic rules of check are .... , ... and ....

74. Geometric similarity ensures .... and .... of design.
75. Optimal design mean the .... of all feasible designs.
76. Value analysis is an organized system of techniques for .... and removing .... costs.
77. Alter-Techniques means alteration of .... in engineering design.
78. The work 'styling' refers to .... and ornamentation.
79. ISO stands for........ .
80. Total Quality Management (TQM) is defined as a .... approach to an organisation centred on ....
81. The basic purpose of the quality series standards is for a .... to be able to establish product .... and .... the customer.
82. The melting point of the filler metal in brazing should be ....
83. It is generally said that a scientist merely explores that which exists, while the engineer .... that which never existed before.
84. .... of alternative solutions consists of manipulating memory to bring together already available ideas in a new form to yield desired new results.
85. Thermostat is an example of .... loop system.
86. .... is needed to plan, organise and direct the design.
87. Probabilities design methods involve with more versatile mathematical systems which takes into consideration both .... value and ....
88. Scale .... test is one of the main type of test to qualify the design concept.
89. Development test conducted for qualifying the design concept are used to check the .... of the design.
90. Phenomenon of weld decay occurs in .... steel.
91. Computer systems fall into three reasonably well-defined categories: mainframe, ... and........ .
92. Minicomputers are generally considered to be small machine with a word size of .... to .... bits.
93. Devices such as video-display terminals (VDTs), also known as cathode-ray tubes (CRT's) are used for both .... and ....
94. The software of CAD/CAM is collection of computer .... stored in the system to make the various hardware components perform specific tasks.
95. Operating systems are programs written for a specific .... or class of ....
96. Visual .... are an important part of any .... presentation; good ones can increase the audience retention of your ideas by 50%.
97. The chief purpose of a visual aid is to improve and simplify ....
98. Communication can be simply described as the flow of .... from one mind to ....
99. The philosophy behind the identifying customer needs is to .... a high .... information channel.
100. The customer needs are largely .... of any particular product we might develop.

101. User programs in CAD/CAM are highly specialised packages for creating specific ....

102. Computers perform various management tasks such as inventory .... and .... system.

103. Jointed arm (revolute) type of robot contains rotary joints called .... and elbow.

104. The non-servo point-to-point robot is also known as a robot ....

105. Continuous-path robots utilise the same type of feedback as the point-to-point robots but store the data on a .... basis.

106. The robot controller is a special purpose ....

107. The robot control system usually have two main components that provide the adaptive control : the robot control unit (RCU) and the ....

108. Two distinct meanings may be given to quality, namely, quality of .... and quality of ....

109. .... quality characteristic examples would be wattage thickness, specific gravity etc.

110. For any product a certain amount of .... is always specified.

111. The concept of .... implies the study of quality characteristics through which a process is judged for conformance or acceptability.

112. .... variation is uneconomical to eliminate and always takes the same pattern.

113. Long wires are made by ....

114. Studies of communication in business organisations have shown that geographic proximity is a .... factor in .... communication.

115. The product control refers to the schemes of evaluating the quality of .... product.

116. The first principle of written communication is to know your .... so that you can anticipate and fulfill its ....

117. The most appropriate type of delivery for most business-oriented talks is an extemporaneous .... talk.

118. Modern quality control has .... approach to the quality function.

119. Quality has a meaning in .... the stages of products.

120. The so-called eight M's are the fundamental .... which affect quality product.

121. The major function of quality is achieving .... for use.

122. Every position in quality control management should have .... along with responsibility.

123. The quality of a product visualised from .... to .... is known as total quality.

124. We define prototype as an .... of the product along one or more dimensions of interest.

125. Tolerances cover dimensional .... and surface roughness ....

126. A technical model of the product is a tool for .... the value of matrices for a particular set of design decisions.

127. A system may be defined as an interconnected complex of .... related components designed to achieve predetermined objective.

128. Information system is defined as the system which .... and .... data and disseminates or spreads information
129. A typical modern factory employs microprocessors in virtually every respect, from .... scheduling to .... and .... control.
130. The collection of program, together with the data used by the programs and documentation describing them is known as ....
131. Computer-integrated manufacturing (CIM) is the interfacing of all of the various .... into a unified system.
132. The software is designed to interface with various preprocessors for NC .... tools.
133. Decision tables provide an alternative way to develop and document manufacturing knowledge and offer numerous advantages over .... charts.
134. The .... concept may be thought of as an extension of SQC concept in predicting the behaviour of a complicated system.
135. The two important principles of quality control are principle of .... and principle of ....
136. .... costs include such loss elements as scrap, spoilage, rework etc.
137. As quality is .... job in a business there is always a danger that it may become .... job.
138. Physical prototypes are tangible artifacts created to .... the product.
139. Analytical prototype represents the .... in a non-tangible, usually mathematical manner.
140. Prototypes are used for four purposes : learning, ... integration and milestones.
141. A drawing made to provide the information necessary for doing work of any kind is called a .... drawing.
142. Assembly System Design Program is a .... program based on dynamic programming capable of synthesising manufacturing systems.
143. 'Liaison Sequence Analysis' is a method for identifying all possible ways to .... a product starting from Liaisons between parts, where a Liaison may be a process, a test, or the physical .... of two parts.
144. A database is a complete collection of .... or raw facts, which represents on organisations information resource.
145. The elements of database management include recognition of .... management problems; desing activity leading to collection, storage, and .... of data.

ANSWERS

1. Gravity die casting, pressure die casting
2. Hand ramming, jolting, squeezing
3. 20000 to 30000 Hz
4. 10^5 to 10^{10}
5. Plastic welding, fusion welding
6. tensile, impact, bend
7. Aluminium silicon alloy copper phosphorus alloy
8. tapered
9. hollow spaces
10. flow of
11. hard
12. 850-1140°C
13. beam of light

14. 3 : 2
15. grit
16. tolerance
17. 1 mm greater
18. batch
19. centrifugal
20. air
21. continuous
22. increase
23. increases
24. tool
25. rolling
26. evolutionary traditional
27. nominal
28. unequal
29. swell
30. broaching
31. Electric discharge machining
32. nickel
33. analog
34. star
35. information
36. discontinuous
37. dressing
38. electrical discharge
39. blank
40. thermal
41. refine
42. investment
43. tactile sensor
44. seven
45. On-board batteries
46. need
47. optimum
48. preventive
49. ductility
50. low
51. Ideation
52. ideas
53. assembly
54. conceptual, preliminary, detailed
55. optimum
56. break down
57. Draft
58. shear plane
59. neutral
60. melting ablation
61. intricate
62. scale formation
63. melting and erosion
64. capillary action
65. hot hardness
66. process
67. planning
68. computer
69. visual
70. pixels
71. on board batteries
72. flaws and defects
73. clarity, simplicity, safety
74. simplicity, clarity
75. best
76. identifying, unnecessary
77. technology
78. decoration
79. International Organisation for Standardisation
80. management, quality
81. company, integrity, safety
82. 420°C
83. discovers
84. synthesis
85. closed
86. Information
87. mean, variance
88. model
89. rigidity
90. stainless
91. minicomputer, microcomputer
92. 12, 32
93. input, output
94. programs
95. computer, computers
96. aids, technical
97. communication
98. intelligence, another
99. create, quality
100. independent
101. output
102. control, scheduling
103. shoulder
104. pick and place
105. time
106. brain
107. sensor control unit (SCU)
108. design conformance
109. Measurable
110. tolerance
111. control
112. Natural or inherent
113. drawing
114. major, enhancing
115. inprocess
116. language, needs
117. prepared
118. integrated
119. all
120. factors
121. fitness
122. authority
123. cradle, grave
124. approximation
125. variation, range
126. predicting
127. functionally
128. collects, processes
129. production, manufacturing, quality
130. computer software
131. manufacturing modules
132. machine
133. flow
134. reliability
135. coordination, prevention
136. Failure
137. every body's, no body's
138. approximate
139. product
140. communication
141. working
142. computer
143. assemble, making
144. data
145. data, retrieval

A.M.I.E. Section–A Question Paper

JUNE-2005

FUNDAMENTALS OF DESIGN AND MANUFACTURING

Time : Three hours ***Maximum marks : 100***

Answer Five questions, taking Any Two from Group A
Any Two from Group B and All from Group C.
All parts of a question [(a), (b) etc.] should be answered at one place.
Answer should be brief and to the point and be supplemented with neat sketches. Unnecessary long answers may result in loss of marks.
Any missing data or wrong data may be assumed suitably giving proper justification.
Figures on the right hand side margin indicate full marks.

GROUP A

1. (*a*) Discuss the stages in engineering design process with the help of example. 6

(*b*) Differentiate between standardization and specification giving appropriate examples. How are 'preferred numbers' useful in standardization'? Explain with the help of a suitable example. 8

(*c*) Explain in brief: 6

(*i*) Robust design

(*ii*) Role of brainstorming in design idea generation.

2. (*a*) What is the role and importance of aesthetics in design? What are the important aesthetic design requirements? Discuss. 6

(*b*) In a system there are four components in parallel followed by the components in series. The components in parallel have a reliability of 0.7 each and those in series have a reliability of 0.8 each. Determine the reliability of entire system.

Define the terms:

(*i*) Reliability

(*ii*) Mean time to failure, and

(*iii*) Mean time between failure. 8

(*c*) Write short notes on: 6
(*i*) Design communication
(*ii*) Tools of information technology.

3. (*a*) Explain, with diagram, a process for the production of seamless tubes and pipes. 6
(*b*) Define Shrinkage and Porosity in castings. How can one tell whether cavities in castings are due to porosity or shrinkage?
How are dissolved gases removed from castings? List four casting defects. 8
(*c*) What checks are recommended for ensuring design's clarity, simplicity, modularity and safety? Explain. What is design for maintenance? 6

4. (*a*) What are the major classifications of basic manufacturing processes? Highlight the characteristics of each and its specific applications (at least two). 6
(*b*) How would you give the specifications for a (*i*) lathe machine, (*ii*) milling machine? 6
(*c*) Explain Investment Casting Process with the help of neat diagrain(s). What are its applications? 8

GROUP B

5. (*a*) What is Computer Aided Process Planning? How is it superior to manual process planning? Explain? 6
(*b*) On what basis parts are grouped into families in Group Technology? Discuss citing examples. What are the benefits of GT over the conventional setup?
(*c*) What are the differences between conventional and non-conventional machining processes? List three finishing operations commonly used in manufacturing? Why are these operations necessary? Explain.

6. (*a*) What is an FMS? What are its components? Why do FMS require major capital expenditure? And why is an FMS capable of producing a wide range of lot sizes?
(*b*) With the help of schematic illustration, describe the principle of operation of EDM process. 6
(*c*) Explain the tool-work interaction process and mechanism of chip formation. Represent the interaction with the diagram. 8

7. (*a*) Define modelling and simulation. 'Simulation is a type of modelling', justify giving an example. 6
(*b*) Explain (*i*) Robots and (*ii*) Automated Storage and Retrieval Systems (AS/RS) material handling systems. Highlight their components, working and applications.
(*c*) What is design for manufacturability? How can it be realised in practice? Explain with an example. 6

8. (*a*) Schematically represent the surface grinding process. What are the components of a surface grinding machine? List some applications of surface grinding. 6
(*b*) Describe the basic fusion welding process. Explain the process details of submerged arc welding. 6
(*c*) Explain the following in brief: 8
(*i*) Design for economic manufacturing
(*ii*) Basic tools of integration
(*iii*) Information technology and its elements.

GROUP C

9. (*A*) For each question, select the *correct answer* out of the alternatives provided. 1×12

(*i*) Which one of the following is not a function of a riser?
- (*a*) To help the flow of metal towards the mould cavity.
- (*b*) To provide escape to hot gases.
- (*c*) To feed the metal to the casting as it shrinks during solidification.
- (*d*) To help streamline the flow of metal into runner.

(*ii*) The required cutting speed in metre/min in machining a workpiece with a diameter of 100 mm and a speed of 500 rpm will be
- (*a*) 628 (*b*) 262
- (*c*) 157 (*d*) 37.7.

(*iii*) Quick return mechanism is used in
- (*a*) slotter (*b*) broach
- (*c*) milling (*d*) lathe.

(*iv*) The collapsible toothpaste tubes are produced by
- (*a*) impact extrusion (*b*) direct extrusion
- (*c*) indirect extrusion (*d*) tube extrusion.

(*v*) Aluminium oxide abrasive is used for grinding
- (*a*) gray cast iron (*b*) high speed steels
- (*c*) cemented carbides (*d*) ceramic materials.

(*vi*) Which of the following materials is used as the dielectric fluid in electro-discharge machining?
- (*a*) Kerosene (*b*) NaCl
- (*c*) NaOH (*d*) $NaNO_3$.

(*vii*) Wax pattern is used in
- (*a*) die casting (*b*) shell moulding
- (*c*) investment casting (*d*) plaster moulds.

(*viii*) The material used for coating the electrode is called
- (*a*) flux (*b*) slag
- (*c*) deoxidiser (*d*) binder.

(*ix*) Casting is a preferred process for parts having
- (*a*) a few details (*b*) many details
- (*c*) non-symmetrical shape (*d*) none of the above.

(*x*) Size of shaper is specified by
- (*a*) size of table (*b*) h.p. of motor
- (*c*) ratio of forward to return stroke (*d*) length of stroke.

(*xi*) A standard ground drill has a point angle of
- (*a*) 90° (*b*) 100°
- (*c*) 118° (*d*) 120°.

(*xii*) When the grains of a grinding wheel become dull, then it must be
- (*a*) replaced (*b*) turned
- (*c*) dressed (*d*) treated.

ANSWERS

(*i*) (*b*), (*ii*) (*c*), (*iii*) (*a*), (*iv*) (*a*), (*v*) (*b*), (*vi*) (*a*), (*vii*) (*c*), (*viii*) (*a*), (*ix*) (*b*), (*x*) (*d*), (*xi*) (*c*), (*xii*) (*c*).

(B) Write briefly about the following giving an example wherever applicable: 2×4

(*i*) Design for recyclability (*ii*) Ergonomics

(*iii*) Automomated Guided Vehicles (AGVs)

(*iv*) System concept.

❑❑❑

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